S. HRG. 101-53

ARCTIC AND ANTARCTIC OZONE DEPLETION

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

UNITED STATES SENATE

ONE HUNDRED FIRST CONGRESS

FIRST SESSION

ON

ARCTIC AND ANTARCTIC OZONE DEPLETION

FEBRUARY 23, 1989

Printed for the use of the
Committee on Commerce, Science, and Transportation

U.S. GOVERNMENT PRINTING OFFICE

96-261 O WASHINGTON : 1989

5261-36

For sale by the Superintendent of Documents, Congressional Sales Office
U.S. Government Printing Office, Washington, DC 20402

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ARCTIC AND ANTARCTIC OZONE DEPLETION

THURSDAY, FEBRUARY 23, 1989

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE,
Washington, DC.

The Committee met, pursuant to notice, at 9:37 a.m., in room SR-253, Russell Senate Office Building, Hon. Albert Gore, Jr. (chairman of the subcommittee) presiding.

Staff members assigned to this hearing: Mike Nelson and Penny Dalton, professional staff members; and Sherman Joyce, minority staff counsel.

OPENING STATEMENT BY SENATOR GORE

Senator GORE. The hearing will come to order. I want to start by welcoming our guests and expressing to each one of them our appreciation for the testimony will hear. I apologize for our starting just a few minutes late.

I want to particularly welcome the scientists on the first panel from the National Aeronautics & Space Administration and the National Oceanic & Atmospheric Administration, because they have just returned from a history-making expedition to the Arctic and their work will of necessity be reflected in our policy and in no small way in our very way of life. I also want to welcome our witnesses on the second panel from business and industry who are on the front lines of this real world battle.

The scientists on our first panel have used the most complicated instruments and the most sophisticated measuring devices to examine a complex threat that has been for many Americans something that somebody else should worry about.

For most families, understandably, the depletion of stratospheric ozone is not nearly as pressing a concern as the mortgage payment, so maybe it is not surprising that when these scientists returned from the Arctic the first question they faced at a news conference where they discussed their findings was from a journalist looking for explanations in plain language, and she was speaking for a large portion of the public.

Yet as they made clear in that conference, and as I hope will be made even more clear here today, there are compelling reasons to turn this prevailing disinterest into activism. For example, there are now clear warnings of severe economic and social disruptions in the coming decade, the 1990s, unless we move now to reverse the deterioration of our environment.

Ozone depletion is one of the key factors in those warnings. Destruction of the earth's protective ozone shield in the upper atmosphere will mean, according to the scientists, lost protection from the sun's most damaging ultraviolet rays and an increase in skin cancers and cataracts.

Estimates are that for every 1 percent depletion of the ozone layer, and there have been several percent depleted already, there will be a 2 percent increase in the incidence of skin cancer. Worldwide some 100,000 people each year die from the deadliest forms of skin cancer, and of course millions of others contract the less deadly forms.

Since 1969, in the U.S. alone ozone concentrations above the continental United States have decreased 2 to 3 percent, some argue somewhat more. The mathematics, then, are obviously quite deadly.

What may be much worse is that destruction of the earth's protective ozone shield threatens damage farther down the food chain and threatens thousands of plants and crops in ways that scientists have not yet fully measured, and already has resulted in damage to some of the most basic organisms at the bottom of the food chain, the phytoplankton, or the simple sea vegetation in the oceans of the world, particularly in the southern ocean—vegetation that sustains the smallest fish to the largest whale.

Scientists tell us that this problem exists now. The seasonal ozone hole in the upper atomsphere above Antarctica reaches the size of the continental United States. Moreover, conditions at the Arctic, as we will hear today, present a time bomb that could cause similar problems and worse.

We know what is punching these holes in the ozone layer: a family of chemicals called chlorofluorocarbons. We put them up there with aerosol sprays, automobile air conditioners, styrofoam and other products. The sad truth is that most of the CFCs we have dumped into our environment have not even reached the upper atmosphere yet.

As a result, between today and the year 2000, the quantity of these chemicals in our upper atmosphere will have doubled. If we think we have a problem now, ten years from now we will have a much bigger problem, because as these scientists will tell us, in the Arctic and Antarctic, the amount of damage done by these chemicals increases by the square of their concentrations.

In other words, as they increase by a factor of 2, the damage increases by a factor of 4. Stated as simply as possible, this is one of the most serious environmental threats that our planet has ever faced, and of course as is by now well-known, the very same chemicals that are responsible for virtually all of the destruction of the ozone layer are also responsible for up to 20 percent of the greenhouse effect, or the global warming problem.

Importantly, it is a challenge that we can meet. It may well mean changes in the design of our refrigerators and automobile air conditioners and other products. It may mean we can no longer go to the store and buy freon off the shelf, but as the respected journal "Science" recently stated, that is a small price to pay when one considers the alternative: the loss of the global ozone layer and the resulting havoc wreaked upon much of the life on earth.

We know that reducing our emissions of these chemicals by recapture, recycling and eventual replacement will reduce the environmental risk. In the coming months, this hearing will be followed by another to focus on the impacts of ozone depletion and the policy responses needed to stimulate international cooperation to control emissions of ozone-depleting chemicals.

Indeed, I am looking forward as well to joining the State Department representatives at the meeting coming up in London to discuss similar actions on an international basis.

Today, I and my colleagues are eager to discuss the findings of this expedition to the Arctic and the private sector's progress in developing alternatives to CFCs. There must be a marriage between the scientists and the policymakers.

That is the idea behind legislation that I recently introduced as S. 201, which would among other things mandate a rapid phase-out, a complete phase-out of CFCs. I do not believe we can wait any longer to address this problem.

The Montreal Protocol, which the Senate ratified last year, put in place international limits on CFC production, but an effective 35 percent reduction by the end of this century, as the protocol requires, is far too little, far too late. The scientists tell us there must be at least an 85 percent reduction just to stabilize the rate of damage, not to reduce the rate of damage but just to stabilize the rate of damage.

So the scientists who have come here today represent our first defense against global environmental threats like the one we are discussing in this hearing. Recognizing what is happening to our planet will show us what measures we must take to halt the damage. We need a broad international effort to monitor and understand the earth so that we can respond wisely to the global environmental crisis from ozone depletion and global warming to deforestation and acid rain.

Now I want to recognize Senator Kasten.

OPENING STATEMENT BY SENATOR KASTEN

Senator KASTEN. Mr. Chairman, thank you very much. I just want to say I am pleased you scheduled this hearing today. It complements the full committee's hearing yesterday on global warming, and also S. 169. The problem of atmospheric ozone depletion is frankly a scary phenomenon. The ozone layer is the earth's protection from the ultraviolet rays of the sun, and its maintenance is necessary for life on this planet.

Since 1965 we have had the disturbing evidence that a hole in the ozone layer existed over the Antarctic region during different times of the year. The recent observations have continued to verify the existence of the problem, though its severity has varied from year to year. From the news reports, the Arctic expedition we shall hear about today unfortunately confirms that the problem exists in the Arctic region as well as the Antarctic.

The world community was shocked enough by the findings on ozone depletion over the last two decades to finally enter into the Montreal Protocol in 1987. On the positive side this international

agreement will result in a reduction by 1998 of the worldwide use of CFC's to one-half of 1986 levels.

However, the facts remain that this agreement was 20 years in coming, and the effects of the CFC's in ozone depletion are cumulative. Further, there are other ozone depleting gases that are not addressed by the protocol. Perhaps with the more recent studies, the established international cooperation with regard to ozone, and the coordinated scientific efforts that the U.S. will hopefully be undertaking, the necessary international attack on stratospheric ozone depletion will proceed faster in the future than in the past.

I stress that the effort must be international in scope, and must be based on good scientific information.

The search for alternative substances must proceed and government must be sure that it is aiding that process, not hindering it. In regard to some of these aspects of the problem I look forward to the testimony of the witnesses on the second panel.

The United Nations Environment Program should be sure not to rest on the achievement of the Montreal Protocol, but must follow up with regard to evidence of other problem substances and review the facts and scientific knowledge in this field on an on-going basis.

I look forward to working with you, Mr. Chairman, and others in the Congress, the Administration and other interested parties as we strive to solve the problem of ozone depletion. It truly may be a matter of life and death.

Senator GORE. Senator Lott.

Senator LOTT. Just briefly, I am pleased to be here. I am glad you are having this hearing. It is an educational process for me as a new member, and I am looking forward to hearing the testimony of the witnesses you have and working with you in the future on this legislation.

Senator GORE. Thank you very much. Senator Kerry.

OPENING STATEMENT BY SENATOR KERRY

Senator KERRY. Thank you, Mr. Chairman. I want to thank you very much for holding this hearing and taking leadership in this area, which I think cannot be understated in its importance.

As you said in your opening and as we discussed yesterday, and as more and more people are now becoming aware, things may be happening far more rapidly than anyone anticipated. Obviously the educational process which these hearings provide for the country and for us as policymakers is critical.

It is important to note that for some 15 years, 15 long years for some people, scientists have been warning us about the impact of the release of chlorofluorocarbons into the atmosphere. We know that the release of these chemicals will result in damage to the ozone layer and a complicated series of negative effects ranging from increased potential for skin cancer, which will affect thousands of our citizens, to increased incidence of cataracts.

In addition to that, and most significantly, and I think something that we still have to learn a lot more about, is the impact on the oceans: the possible depletion of plankton, which in itself can have an enormous negative impact on the ecosystem on which so many nations depend.

In addition to that, the chemicals that cause depletion of ozone contribute to the problem of the greenhouse warming and so all in all we face a series of consequences which, as you said in your opening statement, if you look at the potential for the damage, is about as serious as you can get in terms of any problem that I think we have talked about environmentally.

What is equally disturbing is the fact, as I understand it, that even if we stop today, which we all know we are not going to, the current emission levels of chlorofluorocarbons is such that and their half life is such that they will continue to cause damage at the current rate merely by virtue of what is there. That in and of itself, given what we may learn today regarding potential for damage to the Arctic ozone, though there is no hole yet, is equally disturbing.

So I think your legislation, which I am pleased to be a co-sponsor of, Senate 201, is most important at this time. I do not think we can underemphasize the need to take critical action at this point, and I look forward to hearing from industry representatives about their steps to move rapidly to try to immediately supplant the use of chlorofluorocarbons with other substances which will be environmentally safe and economically feasible.

So I thank you for the hearing, and I look forward to hearing the testimony.

Senator GORE. Well, thank you very much, and we will move right into the first panel but at this point I have an opening statement that the Chairman, Senator Hollings, would like to have included in the record.

[The statement follows:]

OPENING STATEMENT BY THE CHAIRMAN

Man has only been on earth for a very small fraction of its history. Before man came along, the earth's flora and fauna got along quite well. It is clear that nature can survive without man. It is also clear that man cannot survive without nature.

Today's hearing of the Senate Science, Technology, and Space Subcommittee will focus on one way man's activities are threatening nature by depleting the ozone layer. Besides examining current research on depletion of the stratospheric ozone layer, we also will examine possible remedies, ways to replace the chlorofluorocarbons responsible for ozone depletion.

I am glad that Senator Gore has called this hearing on the very serious problem of ozone depletion. The theory that CFCs can cause ozone depletion has been with us for fifteen years. But the first clear evidence of ozone depletion, in the form of the Antarctic ozone hole, only has been available for about 4 years. Although the story of ozone depletion is neither new nor a front page story, the increasing seriousness of this issue cannot be denied. The data obtained during the recent Antarctic and Arctic mission indicates that depletion of the ozone layer continues and that the problem may be even worse than we thought.

Like greenhouse warming, ozone depletion is a global problem which will require an international solution. The Arctic ozone expedition is part of that international solution. In January, dozens of scientists from around the world gathered in northern Norway to search for an Arctic ozone hole. Scientists from the U.S., Norway, the United Kingdom, Germany, the Soviet Union, and many other countries all worked together to gather badly-needed data on the earth's fragile ozone layer. Such cooperation is essential if scientists are to get data from every corner of the globe. For example, without U.S.-Soviet cooperation, we could not get data from the Soviet Union which covers one-sixth of the world's land surface. Such a data gap would leave a very big hole in our understanding of this issue and in our ability to prescribe remedies.

Besides being an example of how countries can work together, the Arctic ozone expedition was an example of how Federal agencies could work together. American

scientists from the National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration played key roles in the expedition, as did university researchers funded by the National Science Foundation. Each participant brought its expertise to the expedition, and they worked very well together just as with the National Ozone Expeditions in Antarctica which preceded it.

I recently introduced S. 169, the National Global Change Research Act of 1989, in order to ensure such effective interagency coordination. More than half a dozen agencies are spending almost a billion dollars on research and development which is helping us understand how our planet works and what impacts man is having upon it. Such a large effort must be well-coordinated and my bill provides for an effective mechanism to accomplish that. Simply put, S. 169 eliminates much of the threat of interagency turf wars over global change research and lets scientists get on with the business of figuring out what we are doing to our global environment and how to prevent it, rather than worrying about which agency has responsibility.

I salute the scientists who are working to solve problems like the cause and effect of depletion of the ozone layer and possible remedies. Their task is a difficult one, to understand the incredibly complicated interacting processes that make our planet livable. Luckily, we have some of the most talented scientists in the world working on this problem. Many years of Federal funding for science have nurtured a corps of world-class scientists who can tackle this problem and provide policymakers like us with answers to our questions about global environmental problems. Those answers are essential if we are to wisely address questions like ozone depletion.

Thanks to excellent scientific information, policy-makers were able to agree on the Montreal Protocol and its international regulations on CFC production. Our first panel today will discuss whether the Montreal Protocol goes far enough. Our second panel of CFC manufacturers and users will discuss the problems that industry will have meeting the Montreal Protocol deadlines. The committee will hear about research and development on replacing CFCs, about the progress that researchers have made, and about the problems that remain. And we will hear whether federal research and development efforts are helping with the transition to CFC alternatives.

I look forward to reviewing the testimony presented at this hearing. The new research from the Arctic makes it clear that ozone depletion is a problem which will be with us for decades and perhaps centuries to come. I am glad that this Subcommittee is a part of calling attention to the problem and finding a solution.

Senator GORE. Let me call them to the witness table. Dr. Robert T. Watson, with the Earth Science & Applications Division at NASA. Dr. Adrian F. Tuck at the Aeronomy Lab with NOAA, and Dr. Susan Solomon with the Aeronomy Lab in NOAA as well. We are honored to have the three of you with us today. Thank you very much for coming.

I think you must have appeared on prior occasions. I know that I chaired a hearing about a year and a half ago on some of these related phenomenon, and was pleased to be able to talk with you at that time, well before this most recent expedition.

You have come back with some brand-new findings. I think we will start with you, Dr. Solomon. Without objection, whatever prepared statement you have which you have presented to us will be put in the record and you are free to highlight it or present all of it, as you see fit.

STATEMENTS OF DR. SUSAN SOLOMON AND DR. ADRIAN F. TUCK, AERONOMY LAB, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION; AND DR. ROBERT B. WATSON, EARTH SCIENCE AND APPLICATIONS DIVISION, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. SOLOMON. Thank you. Well, Mr. Chairman and members of the subcommittee, I certainly appreciate the opportunity to discuss polar ozone with you today.

I am going to try to summarize the status of current understanding, particularly of Antarctic ozone depletion, drawing from studies by members of the international scientific community, and I would like to briefly describe my own view of some of the important similarities and differences between the Arctic and the Antarctic stratospheres.

The study of atmospheric ozone, and concern about its possible depletion, dates back a few decades or so. Theoretical studies of the chemistry of ozone carried out before the discovery of the Antarctic ozone hole suggested that the continued use of chlorofluorocarbons might be expected to deplete ozone by 5 percent some time in the middle of the next century.

But in 1985, scientists from the British Antarctic Survey reported observations of a remarkable change in the Antarctic ozone. The British study and later work showed that the total ozone abundance over Antarctica decreases by about 50 percent during the Southern Hemisphere spring. The decreases are concentrated in the altitude region from 15 to 20 kilometers, where the local depletions can be as large as 95 percent.

The discovery of a 50 percent decrease in the contemporary atmosphere, rather than in the next century, clearly showed that something was influencing polar ozone in an unexpected and dramatic fashion. Laboratory, field and theoretical studies over the past three years since the discovery of the ozone hole have led to an increasingly clear picture of how that takes place.

The key to Antarctic ozone depletion is the extreme cold temperatures that occur in the Antarctic stratosphere. The temperatures are cold enough to allow polar stratospheric clouds to form. The occurrence of the clouds changes the chemistry in a simple and very fundamental way. It allows reactions to occur on surfaces rather than between gas molecules.

Recent laboratory studies have shown that clouds composed of nitric acid and water will form at the temperatures typical of the Antarctic and Arctic stratospheres, but not significantly at any lower latitudes, and chemical reactions take place on those surfaces which convert chlorine from forms which do not react with ozone to other, less stable forms which readily break up in the presence of sunlight and go on to destroy ozone rather rapidly.

Antarctic ozone depletion does not take place during winter, when temperatures are coldest and the polar regions are largely in darkness, but rather in the spring, when the sunlight returns and temperatures remain relatively cold.

A key molecule is chlorine monoxide which is produced by those processes and is involved in all of the ozone-destroying reactions. It is also critical to note that the abundance of chlorine monoxide is closely related to that of the nitrogen oxides.

Chemical reactions involving chlorine and nitrogen oxides control how long the chlorine liberated by those surface reactions remains available to destroy ozone. So, the nitrogen is really as important as the chlorine.

The formation of nitric acid clouds and chemical reactions that take place on the surfaces of those clouds play a dual role. They enhance the abundances of chlorine compounds that can destroy ozone and they decrease the abundances of nitrogen oxides that

can limit the time during which the reactive chlorine remains available for further ozone destruction.

The net effect of both processes is not only to make chlorine available to destroy ozone, but also to allow it to remain available for an extended period of time.

Senator GORE. Because the nitrogen is destroyed also?

Dr. SOLOMON. The nitrogen can be either taken up on the clouds or even removed if the cloud particles get big enough to fall.

Senator GORE. Excuse me.

Dr. SOLOMON. You can only halt the process by reintroducing nitrogen oxide molecules which reconvert chlorine to the inert forms that were there before the clouds entered the picture.

There are a lot of observations that support and extend this picture. I do not have time to go into all of them, but what I want to emphasize is that first and foremost among these are the observations of chlorine monoxide by both aircraft and ground-based methods. These observations show that the abundance of that species is about 100 times greater in the Antarctic stratosphere than observations at middle latitudes or theoretical predictions that do not include the chemistry of the clouds.

The observed levels of chlorine monoxide are sufficient to explain a significant fraction of the ozone loss observed during the austral spring of 1987. Chlorine dioxide is a closely-related molecule which is formed from chlorine monoxide in the presence of bromine oxide, and its abundance was also shown to be enhanced by a factor of 100 in the Antarctic stratosphere.

The abundances of the oxides of nitrogen were, in contrast and in keeping with what I have just said, far smaller than those obtained at other latitudes. Measurements of the total amount of reactive nitrogen in the Antarctic stratosphere in September of 1987 show that the stratosphere had actually been denitrified by falling cloud particles. So the nitrogen oxides were not just temporarily reduced, they were actually removed altogether, and that finding is of fundamental importance to the extent of the ozone loss because it implies that chlorine monoxide will continue to destroy ozone, effectively until air containing more reactive nitrogen is reintroduced.

Observations of hydrochloric and nitric acid column abundances also show perturbations believed to be due to polar stratospheric cloud chemistry and observations of the clouds themselves have been carried out from satellites and aircraft, as well as from several ground-based stations in Antarctica.

These observations form a self-consistent picture, and I really want to emphasize the self-consistency here. They are based on several independent experimental techniques, and they all show that the composition of the Antarctic stratosphere is highly perturbed by the presence of clouds.

The broad range of techniques used and the consistency of the observations has convinced even the most skeptical of our scientific colleagues. There is no longer any question that these perturbations account for a substantial fraction of the Antarctic ozone loss.

Natural variability, especially that introduced by meteorological processes, does play an important role. Some Antarctic winters are, for example, warmer than others and likely to exhibit fewer clouds.

The winter of 1987 in Antarctica was one of the coldest ever recorded, while those of 1986 and 1988 were much warmer, with correspondingly smaller ozone losses. Nevertheless, the observations obtained in those warm years also show that chemical reactions played an important role in depleting the Antarctic ozone at that time.

There are also some important feedbacks between chemical and meteorological effects. Cold temperatures lead to clouds, which enhance reactive forms of chlorine and deplete ozone. Ozone provides a major source of heat for the stratosphere, so decreased ozone is going to make the stratosphere colder, further increasing the occurrence of clouds and keeping the temperatures colder much later into the spring season, allowing more sunlight to be present.

Observations and theoretical studies of a temporal evolution of the 1987 Antarctic ozone hole certainly show that sort of a runaway effect played an important role in the ozone depletion observed in that year, and it illustrates the fact that the onset of large ozone depletion can be extremely sudden and not simply related to the rate of increase of chlorine in the atmosphere.

There are a lot of important differences between the Antarctic and Arctic stratospheres. Satellite and ground-based data show that the ozone depletion in the Arctic is so, far much, smaller than in the Antarctic.

The warmest recorded Antarctic stratospheric winter was still several degrees colder than the coldest Arctic winter, and that is due primarily to a greater tendency for warmer air masses from lower latitudes to push into the polar regions in the Arctic as compared to the Antarctic.

Those intrusions not only keep the Arctic stratosphere generally warmer than the Antarctic, they also lead to greater natural variability in temperatures and in ozone, and finally they help to warm up the stratosphere far earlier in the spring season as compared to the Antarctica.

That is going to lead to a critical difference in the temporal overlap between the cold temperatures and the sunlight, both of which are required for ozone depletion. But on the other hand, those kinds of intrusions can also push some of the cold Arctic air out of the polar darkness into the sunlight during the winter, which could lead to significant ozone loss in some areas.

All of these factors imply that the unambiguous identification of significant ozone loss in the Arctic in general, and particularly in disturbed conditions, is very difficult because it involves study of a highly variable, dynamic situation.

In Antarctica, the ozone loss of perhaps 50 percent is accompanied by an increase in chlorine monoxide of a factor of 100. Clearly the latter perturbation is much easier to observe than the former. That implies that measurements of chemical species such as chlorine monoxide and dioxide, and the nitrogen oxides can help to evaluate both the present and future potential for ozone loss, even in an environment where identification of ozone loss itself may be very, very difficult.

These are the considerations that motivated studies of the chemical composition of the Arctic stratosphere during the winters of '87 and '88, in which scientists sought to understand the chemistry of

the Arctic during the winter, and determine the extent to which it is influenced by polar stratospheric clouds. This is probably the first step in attempting to evaluate the possibility of Arctic ozone depletion.

This concludes my presentation. Thank you again for the opportunity. I will be glad to answer any questions you might have.

Senator GORE. Well, thank you. We will hold off on our questions until your colleagues have testified. Dr. Watson.

Dr. WATSON. What I would like to do, Senator, is just give you a brief background of why we went to the Arctic in just a couple of minutes, allow Dr. Adrian Tuck then to give you the results, and I would like to then come back to address the Montreal Protocol.

Senator GORE. All right.

Dr. WATSON. Mr. Chairman, members of the subcommittee, it is a pleasure to be here. Obviously, after we noticed and found out that man-made chlorine-containing chemicals were the basic cause for the Antarctic ozone hole, our attention directed to the north.

Here, we have a population much greater underneath the Arctic atmosphere than we do the Antarctic atmosphere, so what we wanted to see was if there was any evidence that there could be something similar going on in the Arctic region.

We conducted a major assessment of ozone trends over the last 30 years throughout the globe. We quickly came to the conclusion that there was only good atmospheric data between 30 degrees north and about 65 degrees north.

Senator GORE. Give us some landmarks so we will know what you are talking about.

Dr. WATSON. Sixty-five degrees north would be somewhere just north of Oslo, right past northern Europe; 30 degrees north would clearly be through the middle of America, so basically through the most populated parts of the globe. North America, all of Europe, and Russia.

Senator GORE. That is the only place where you had a record? Okay.

Dr. WATSON. That is the only place we believed we had good enough definitive data to make strong conclusions about whether there has been a change in ozone or not over the last 30 years. Our key conclusions were very robust. We believe there has been a loss in ozone between 40 and about 65 degrees north, primarily in wintertime, as much as 5 to 7 percent since 1970, that cannot be attributed to known natural variability.

We looked at the record in great detail and we took out all the known natural variability: seasonal effects, changes in solar cycle, changes in meteorological conditions, input from man through the nuclear bomb explosions of the late 1950s and early 1960s, and after taking out all changes, man-induced that we understood or natural, we were left with a conclusion there had been a change in ozone of 5 to 7 percent in the winter.

In addition, we did calculations to see what we would have expected based on the input of fluorocarbons and other manmade gases. And we came to the conclusion that we would only have expected a 1 to 2 percent ozone loss, due to the CFC's in the Arctic winter time.

Clearly, the observed decrease in ozone was greater than theoretically expected.

Next, we looked to see if there were any experimental evidence of perturbed chemistry in the Arctic atmosphere. And there were three lines of evidence. First, over a long period of time, from John Noxon, at the NOAA Aeronomy Lab, we had noticed that the concentrations of nitrogen dioxide, a key nitrogen compound, was extremely low coming out of the polar night, consistent with observations in Antarctica.

Susan Solomon, sitting next to me, also performed some experiments in Thule, Greenland last year, and observed high, elevated concentrations of chlorine dioxide, an indicator of elevated levels of chlorine monoxide, the ozone depleting chemical.

And thirdly, Jim Anderson, from Harvard University has evidence that the abundance of the chlorine monoxide free radical, even on the outside of the Arctic polar vortex, was also elevated by some numbers of 2 to 3.

These three lines of argument show that there was some perturbed chemistry going on in the Arctic. This led us to come to the conclusion a major expedition was needed to the Arctic.

We took the two aircraft, the ER-2 and the DC-8, that we also took to the Antarctic, to Stavanger, in Norway. Approximately 150 to 200 scientists and engineers were involved in the project. We had six balloon sites in Greenland, the Shetland Islands, Norway and in the Soviet Union. We used satellite data to look for polar stratospheric clouds, and meteorological conditions, and we had not only a large team of experimentalists, but a team of theoreticians, who could come up with a quick analysis of the data on the spot.

Now, with that brief introduction, I would like Adrian Tuck to give you the results of that campaign and I would like to return to how I see this fitting into the Montreal Protocol.

Senator GORE. Thank you.

Dr. Tuck, welcome.

Dr. TUCK. Thank you.

Members of the Senate, other attendees, it is a pleasure to be here to talk about the results. The best way that I can try to convey the overall impression in simple terms, non-technical terms, is to say what our reaction was to what we found.

The non-technical way of giving you the overall impact of our conclusions is that by the end of the mission, we were surprised at the extent of the perturbation to the chemical composition of the vortex in the Arctic.

These were mostly people, as Bob said, who were veterans of having been to Punta Arenas and having seen the Antarctic supplemented by some extra theorists and some other extra measurement teams.

So that they were experienced people. And we were surprised at the extent of the perturbation. So that is a quick non-technical way of saying how we felt.

Now, if I can take a bit more time to go through it in detail and I am going to have to use some technical language. I think the first result is that because we went in mid-winter to the Arctic, we saw the perturbation building up as the temperatures dropped, unlike the Antarctic. When we got down there, the perturbation was al-

ready a fait accompli. It was simply a question of the chemistry needing time to destroy the ozone during September, late August and September, in Antarctica.

Here, we got there in mid-winter. We saw the PSC's build up and it was very clear that there were enhanced abundances of the chemically active chlorine compounds that carry the chain reactions that destroy the ozone. They were there. They were very elevated. And before I give any more detail on that, I should say that that build up of the reactive chlorine compounds that destroy the ozone is a result of processing in polar stratospheric clouds. It has greatly enhanced our confidence in that picture. The other important aspect, from a policy point of view, is that those polar stratospheric clouds and the things they do to the chemistry, are not represented in any of the models that we used to calculate the figures on which the Montreal Protocol was based.

Okay, so that is why the PSC's are important, in addition to their scientific importance in causing the perturbation.

Now, the reaction that propagates the chain reaction, the molecule that catalytically destroys the ozone, is chlorine monoxide.

Its abundance was elevated by up to a factor of 50 in the Arctic, compared to what you would either see in models that did not include PSC chemistry, or, indeed, compared to what you would see well away from the Arctic vortex, at the same levels, altitudes.

Consistent with that, the symmetric chlorine dioxide molecule, OClO was also elevated up to a factor of 50. Also, consistent with that, hydrogen chloride, which is the normal form of chlorine which does not do anything to the ozone, was reduced in abundance, and nitric oxide NO and nitrogen dioxide were also significantly reduced.

Those four facts add up to a consistent picture. Consistent with the picture that we had of Antarctica, the chlorine has been processed by the polar stratospheric clouds from inactive into active forms. That is only possible, if, at the same time, NO and NO_2, nitrogen oxides, have been removed and we have got our little piece of litmus paper, the OClO molecule, that tells us, that indeed, there is a lot of ClO in the presence of bromine monoxide, which is universal.

The measurements in the DC–8 indicate that the column abundances of those molecules is such that the perturbation has to extend over a very deep layer of the Antarctic atmosphere.

The lidar measurements of the DC–8 tell us that the polar stratospheric clouds were roughly present at altitudes from about 16 kilometers to 25 kilometers, about a 9 kilometer deep chunk of atmosphere.

Chlorine repartitioning in that layer is consistent with what we saw for the total amount above the DC–8, so that it was a consistent picture.

The picture is different from—it is more similar to the Antarctic than dissimilar, but there are some dissimilarities, and as Susan indicated, the reasons are largely meteorological for those dissimilarities.

The way that those meteorological dissimilarities get reflected in the chemistry is that you do not have the complete, almost complete, denitrification inside the vortex that we had in Antarctica. It

was partial, but nevertheless, an important conclusion that we came up with was that the atmosphere was at least denitrified. It had lost total reactive nitrogen, without very extensive dehydration.

And that is something that is different to Antarctica.

Okay, now, by the end of the mission, there was no unequivocal signature of photochemical loss of Arctic ozone within the vortex. However, some data may be suggestive of ozone loss. Again, we are not dealing with a 50 percent signal here, like we were in Antarctica. We do not have that luxury in geophysical experiments very often, and it is going to take a lot of work to see whether we were actually seeing ozone loss or not by the time the aircraft left.

We have left in place some ozonesondes, and they will continue launching over the next few weeks, but, of course, we do not have all the supplementary information. It is very difficult to look at an ozonesonde ascent and look at a chunk in it and say there is some photochemical ozone loss. That is a very difficult thing to do, you can not do it with confidence.

But at the time that we left, the vortex air was primed for ozone destruction. There is no question about that. On our last flight, we saw 800 parts per trillion of ClO and those are very comparable to the levels of chlorine monoxide that we were seeing on the Antarctic flights.

There are two things that mean that there must be ozone loss going on. As the amount of sunlight increases, in that air that is being denitrified and has got the elevated abundance of ClO, there will be ozone loss, based on our present understanding. The real question is, what rate will it occur at and how long will it go on for?

Now, the best handle that we have got on the rate at which it will occur, there is continual uncertainty on this, but nevertheless, is that it is a few tenths of a percent, per day.

How long will the vortex hold together? Well, our actual predictive scale, using the best numerical weather prediction models, is about 5 days. So, we can tell 5 days ahead of time if the vortex is going to break up. Statistically it should break up fairly soon. So it is a race. Can we get nitrogen back into that air, or can we not, more quickly than the chlorine monoxide will destroy the ozone?

The best handle we have got on the various processes are that they are all about the same time scale, of a matter of several days to a few weeks. The level of exposure to sunlight matters. In other words, how much the vortex bends and wobbles about, and makes excursions down to southern latitudes. The further south it comes, the more sunlight it will get.

The degree of nitrification of the Arctic stratosphere is something that we are not completely certain of, although we had 14 flights of each aircraft. When you look at an aircraft track superimposed on the vortex, you realize that the track is rather small in scale, compared to the scale of the vortex.

But nevertheless, there is a prima facie case for saying that a fairly substantial fraction of the air has been denitrified. And finally, there is the rate at which the atmosphere can mix in air that has not been denitrified with air that has been denitrified.

The best guesses we can make at that are that the scales are from several days to a few weeks, but again, we do not have a very good handle on it. Nevertheless, the position is very clear—we have got an empirical case where we know what happens when it is understood, mainly, Antarctica. And if the vortex does hold together for a matter of a few weeks, then I think it will be very surprising if we do not see some ozone loss.

But I want to repeat, that we do not have a clear, unequivocal signature of that as yet.

Finally, this was not a particularly unusual year, meteorologically, in the Arctic. The perspective we have got is that it can be misleading to look at temperatures that are averaged over a month, or averaged over a large region. Much of the polar stratospheric clouds seems to be forced by a handful of meteorological events connected with ordinary passage of storm systems, highs and lows, in the troposphere.

And if you get one or two of these events, three or four sometimes in a winter, that really push a lot of air poleward, what happens is that they force some very cold temperatures in the stratosphere, locally, on a scale of thousands of kilometers. And there is a great deal of air that flows through that pattern. The pattern lasts for three or four days and the air, the stratospheric air, flows through it very fast.

So, a handful of events can process, by exposing them to PSC's, a large fraction of the air in the vortex. And I think that that is an important perspective, because we know that the chemistry is there. And it depends on what the meteorology does in any one year as to the extent of the ozone damage which will ultimately result.

I am going to use the term nonlinear, and I am going to try and amplify what it means a bit. The chemistry is nonlinear. You gave the example, if you double the chlorine, you have 4 times the effect on the ozone. Well, the meteorology is also highly nonlinear. And the perspective I want to leave you with is that we have a system in which nonlinear meteorology is interacting with nonlinear chemistry and we really are not in very good shape to predict what is going to happen with confidence.

Thank you.

Senator GORE. Dr. Watson?

Dr. WATSON. Thank you, Senator.

What I would like to recap is, where are we today, compared to when the Montreal Protocol was signed in September 1987?

Three things have changed. We have observed the Antarctic ozone hole and established cause and effect between man-made chlorine compounds and the ozone hole. We have observed a decrease in ozone in the northern hemisphere in winter that cannot be attributed to known natural variability. And we have just come back from the Arctic and observed a highly disturbed atmosphere that has a significant potential to destroy ozone.

The first comment that I have to make is the models that were used as the basis for the Montreal Protocol do not include these very important ozone depleting processes that are initiated by the polar stratospheric clouds. Clearly, the models are deficient in processes that can lead to ozone destruction.

Secondly, today there is 3 parts per billion of chlorine in the earth's atmosphere. Even with a fully ratified Montreal Protocol, the amount of chlorine will double to at least 6 or more parts per billion. If our understanding of the ozone hole in Antarctica is correct, then clearly the ozone hole over Antarctica is here forever.

What would we need to get rid of the ozone hole over Antarctica? We need to reduce the chlorine levels back to the levels of the late 1960's or the early 1970's. That is approximately 2 parts per billion as compared to 3 parts per billion today.

I have already stated that under the Montreal Protocol, the chlorine will double. What would it take to get back to 2 parts per billion of chlorine?

In my personal opinion, it would require almost a complete phase out of fluorocarbons 11, 12, 113, 114, 115, and the two major halon compounds. We must understand why carbon tetrachloride is increasing in the earth's atmosphere and we do not at the moment. We must find out why and stop it from increasing. We must consider regulations on methyl chloroform—we cannot allow it to continue to increase in the earth's atmosphere. That is the minimum that we need to do.

As was stated earlier by one of the Senators, these gases have very long lifetimes. Even if we were to stop putting all the fully halogenated compounds into the atmosphere today, the ozone hole will probably exist for centuries into the future.

Time is of the essence. In so far as, for every year that we put more fluorocarbons into the atmosphere, it takes 10 years to get back to that original level. It takes 1 year to put it in, 10 years to get it out because of the long atmospheric life.

So, there is a level of urgency. One thing that is absolutely essential and that is well recognized by the Senators of this panel, is that it is essential to get 100 (percent) international compliance for the Montreal Protocol.

If the developing countries or other developed countries do not, indeed, have a strong ratified Montreal Protocol, then the efforts of the United States, Europe, Japan, and the Soviet Union will be partially to no avail.

I believe the meeting in England that you, Senator Gore, will attend is an essential step towards engaging the cooperation of the developing countries.

Thank you.

[The statement and questions follow:]

STATEMENT OF

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

U.S. DEPARTMENT OF COMMERCE

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE AND TRANSPORTATION

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

U.S. SENATE

Mr. Chairman and Members of the Subcommittee:

We are pleased to be here today to discuss our current understanding of the physical and chemical processes that control atmospheric ozone, globally and in the polar regions.

The preliminary results of the recent expedition to Norway have substantially increased confidence in the scientific understanding of the PSC-induced, chlorine catalyzed, ozone depletion phenomenon. As a result, it is clear that enhancements of chemically active chlorine compounds do indeed occur in both the Arctic and Antarctic stratosphere, and represent an additional ozone-depleting process that was not included in the stratospheric ozone assessment models used as a basis for the Montreal Protocol.

This remainder of this statement was prepared by the scientists who went to Sola Airfield near Stavanger, Norway to study the Arctic winter stratosphere. **The findings given here**

are preliminary. Under normal circumstances, scientists studying such a complex scientific issue would take up to a year or more to disclose their initial findings. However, the issue of global ozone depletion due to human activities is one of justifiable public concern, and hence the public and policymakers should be kept abreast of the current scientific thinking. It is in this spirit that this provisional picture of the processes controlling ozone at high latitudes in winter is given. **This document cannot be referenced as a scientific publication.**

EXECUTIVE SUMMARY

The key findings of the 1989 Airborne Arctic Stratospheric Expedition are as follows:

- The chemical composition of the Arctic polar stratosphere was found to be highly perturbed.
- Specifically, in comparison with the abundances calculated using theoretical models that do not include chemical reactions occurring on the surfaces of Polar Stratospheric Clouds (PSC's)
  - the observed abundance of the ozone-depleting chlorine monoxide radical (ClO) was elevated by up to a factor of 50 in the Arctic lower stratosphere,
  - the abundance of chlorine dioxide (OClO) was increased by up to a factor of 50, consistent with increased abundances of ClO in the presence of bromine monoxide radicals (BrO),
  - the abundance of the major inactive chlorine reservoir, hydrochloric acid (HCl), was considerably reduced, indicating that there had been a conversion from the inactive to the active (ozone-depleting) chemical forms of chlorine, and
  - the abundances of nitric oxide (NO) and nitrogen dioxide (NO_2) were significantly reduced, thereby preventing the reconversion of ClO into an inactive form of chlorine.
- The measurements of the column abundances of several of the above compounds indicate that these perturbations occur over a wide range of altitudes in the stratosphere.
- The above observations add up to a consistent picture that is similar to the one drawn from the Antarctic data in 1987 and are believed to be the result of chemical reactions occurring on the PSC's that form at the cold temperatures.
- The chemical changes were associated with the presence of PSC's and are consistent with the picture of their role in (i) shifting the partitioning between the active and inactive chlorine compounds, (ii) removing the nitrogen oxides (NO + NO_2), and (iii) removing and repartitioning NO_y (the sum of all nitrogen-containing reservoir and radical species).
- No unequivocal signature of photochemical loss of Arctic ozone was identified before the end of this mission. However, by the end of this mission, a considerable portion of the vortex air was primed for ozone destruction.

- It is difficult to predict the degree of Arctic ozone depletion that will actually occur because it depends on the rate at which normal partitioning of chlorine species is reestablished. This rate is uncertain:
  - the level of exposure to sunlight is uncertain,
  - the degree of denitrification of the Arctic stratosphere (indicated by the amount of HNO_3) has not been adequately quantified with respect to altitude, and
  - the rate at which the Arctic air mixes with air containing ambient levels of the oxides of nitrogen is difficult to predict reliably.
- The relevant meteorological conditions for the formation of PSC's in the Arctic polar region were not unusual this year. Hence, the phenomena observed are expected to occur in most years.
- Until a comprehensive analysis of the data from this mission is accomplished and model calculations are performed, it is not clear whether the high latitude winter ozone decreases reported by the International Ozone Trends Panel are due to the perturbed Arctic chemistry.
- The observed PSC-induced buildup of reactive chlorine compounds represents an additional ozone-depleting process that was not included in the stratospheric ozone assessment models used as a basis for the Montreal Protocol.

The preliminary results of this mission have substantially increased confidence in the scientific understanding of the PSC-induced, chlorine catalyzed, ozone depletion phenomenon. As a result, it is clear that enhancements of chemically active chlorine compounds do indeed occur in both the Arctic and Antarctic stratosphere.

BACKGROUND TO THE MISSION

Discovery of the Antarctic Ozone Hole: During 1985 there was a report from the British Antarctic Survey of a large, relatively sudden, and unanticipated decrease in the abundance of Antarctic ozone each spring for the last decade. In 1987, ozone decreases of more than 50% in the total column, and 95% locally between 15 and 20 km, had been observed.

Understanding the Antarctic ozone hole: A change of this magnitude was not predicted by any of the photochemical models, and new hypotheses to explain the phenomenon were immediately forthcoming. One hypothesis suggested that atmospheric chemicals containing chlorine and bromine efficiently destroy ozone in the Antarctic lower stratosphere because of its special meteorological conditions, a very cold air mass largely protected against massive exchange with midlatitude air by the dynamical effects of a band of strong circumpolar winds (polar vortex). The cold temperatures found inside the vortex permit the formation of Polar Stratospheric Clouds (PSC's) whose presence significantly perturbs the chemical composition of the lower stratosphere by allowing heterogeneous chemical reactions (on the PSC surfaces) to occur. These reactions (1) convert chemically inactive chlorine reservoir species (HCl and $ClONO_2$) to Cl_2 and HOCl which in the presence of sunlight produce Cl atoms that chemically react with O_3 and form ClO and (2) remove NO_x ($NO+NO_2$) or NO_y (the sum of all nitrogen-containing reservoir and radical species) and thereby allowing a larger fraction of inorganic chlorine to be present as ClO. Catalytic

destruction of ozone takes place primarily through the subsequent reactions of ClO with itself and with the BrO radical.

Results from the Antarctic campaigns: The ER-2 and DC-8 aircraft campaign from Punta Arenas, Chile in August / September, 1987 and the ground-based observations from McMurdo in August through October of 1986 and 1987 have demonstrated the general validity of the above hypothesis. The results from Antarctica demonstrated that enhanced ozone depletion requires: (a) a largely isolated vortex with temperatures cold enough to produce PSC's and (b) sunlight to drive the chlorine (involving the ClO radical) and bromine (involving the BrO radical) ozone destruction cycles. Substantial amounts of reactive nitrogen (NO_y) and water vapor had been removed, while ClO abundances were on the order of 1 ppbv (parts per billion by volume). In this region, substantial ozone depletions were observed during September. The observed ozone loss was broadly consistent with the observed levels of ClO and the exposure to sunlight. As stated above the removal of NO_y (denitrification) or of NO_x was an essential element in this process, inhibiting the reformation of inert reservoir species, HCl and $ClONO_2$, thereby allowing ClO abundances to remain elevated. The observation of substantial water vapor removal (dehydration) in the denitrified regions suggested that the two processes occurred simultaneously, perhaps through the precipitation of PSC particles composed largely of water ice (Type II PSC's), but containing a trace of NO_y . Such particles formed when the temperatures decreased below the frost point. Following denitrification, perturbed chemistry persisted for some time in the absence of PSC's and hence ozone depletion occurred.

The results from the Antarctic mission led to profound changes in our thinking about stratospheric chemistry and dynamics in the polar regions and increased speculation that similar phenomena might be occurring to a lesser, but important, extent at northern high latitudes.

Ozone loss at northern high latitudes in winter discovered: Concern was heightened by the findings of the International Ozone Trends Panel: ozone was found to have decreased by about 5 - 6% between 40°N and 60°N since 1970 during the winter months, over and above changes attributable to known natural variability. This decrease is greater than that predicted by model calculations based on the historical growth in atmospheric concentrations of ozone-destroying gases.

Furthermore, recent observations of a few key chlorine (ClO and OClO) and nitrogen (NO_2) species in the Arctic winter stratosphere have given preliminary indications of perturbed chemistry.

Nevertheless, all observational data to date demonstrate that there has been no loss of ozone in the northern hemisphere comparable to the springtime losses in the Antarctic region, i.e. there is no Arctic ozone hole.

Similarities and differences between the Arctic and Antarctic atmospheres: The Antarctic polar vortex lasts well into springtime after the return of sunlight to the Pole. In contrast the Arctic polar vortex is warmer and normally breaks down well before the return of sunlight to the Pole. The geographical features of the northern hemisphere permit more vortex distortion during winter. At the warmer temperatures of the Arctic winter, occurrence of Type II PSC's is known to be less extensive. Thus, the degree of denitrification might also have been expected to be less pronounced. Therefore, to study the influence of heterogeneous chemistry on the Arctic vortex, it was necessary to conduct the present campaign in early winter, a period when PSC's are likely to form. This is

equivalent to the preconditioning period (prior to the onset of significant ozone depletion) in the Antarctic, i.e., July through early August.

ARCTIC OZONE CAMPAIGN

This Airborne Arctic Stratospheric Expedition was similar to the one based in Punta Arenas except that it was performed in the middle of winter rather than in late winter / early spring. The campaign utilized two aircraft, a high altitude ER-2 and a modified DC-8 based at Sola Airfield near Stavanger, Norway (59°N, 6°E) from January 1 to February 15, 1989. These aircraft were equipped with state-of-the-art instrumentation (13 instruments on the ER-2, and 10 on the DC-8) for determining the chemical composition and physical state of the atmosphere. Satellite and ground-based measurements were also vital and integral components of the campaign. Teams of theorists participated with the experimentalists in flight planning and in the interpretation of the data. There were 14 flights of the DC-8 and 14 flights of the ER-2, excluding the ferry flights between the USA and Norway. DC-8 flights went as far north as the Pole and as far west as the western coast of Greenland. The ER-2 ranged as far as 82°N and the center of Greenland.

The present campaign was undertaken to examine the chemical and dynamical processes that control ozone in the Arctic winter stratosphere. The overall goal of this mission was:

> **To establish whether the processes that contribute to the Antarctic ozone depletion are operative in the northern hemisphere.**

Thus, the specific goals were:

> To observe and understand the atmospheric conditions that lead to the formation of polar stratospheric clouds (PSC's).
>
> To search for evidence of perturbed chemistry (i.e., different from that incorporated in current atmospheric models which do not include the influence of PSC's).
>
> To search for evidence that the PSC's play a role in perturbing the chemical composition of the Arctic stratosphere.
>
> To observe and understand the impact of chemically perturbed Arctic air on ozone.
>
> To elucidate the role of atmospheric transport in modulating the effects of chemistry.

MISSION ORGANIZATION

The campaign involved several agencies of the U.S. government with international collaboration and the participation of scientists from universities, government laboratories, and private industry.

The campaign was coordinated by the National Aeronautics and Space Administration (NASA) and was cosponsored by the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation, and the Chemical Manufacturers Association. The United Kingdom Meteorological Office, the United Kingdom Department of the Environment, the Norwegian Department of the Environment, and the Norwegian

Meteorological Institute provided major contributions to the project. The European Center for Medium-Range Weather Forecasting and the National Meteorological Center (NMC) also provided some assistance.

Scientists, engineers, and other personnel from the University of Colorado / NOAA Cooperative Institute for Research in Environmental Sciences, University of Denver, Harvard University, Pennsylvania State University, University of Cambridge (UK), University of Oslo (Norway), National Center for Atmospheric Research, Jet Propulsion Laboratory, NASA Ames Research Center, NASA Langley Research Center, NASA Goddard Space Flight Center, NOAA Aeronomy Laboratory, the United Kingdom Meteorological Office, and KFA Jülich (FRG) participated in this campaign.

Balloon-sonde ozone and temperature data were provided throughout the mission from Lerwick, Shetland Islands (by the NASA Wallops Flight Facility); Angmagssalik and Scoresbysund, Greenland (by the Danish Meteorological Institution); Bear Island, Norway (by the Norwegian Institute for Air Research), Spitzbergen, Norway (by the Alfred Wegener Institute, FRG), and Heiss Island, USSR (by the Hydrometeorological Institute, USSR).

Key support was also received during this campaign from the flight and ground crews of NASA, Lockheed Corporation, and Mantech / NSI who flew and maintained the ER-2 and DC-8 research aircraft under very challenging conditions. The NOAA Aeronomy Laboratory provided the necessary telecommunication links and computer support. Sterling Software provided flight track data from the aircraft.

The Norwegian government hosted the airborne campaign, which was based at Sola Airfield near Stavanger, Norway. The Royal Norwegian Air Force supplied the facilities and logistical support.

FINDINGS

(1) Was clear evidence of photochemical ozone depletion found during the mission?

It is too early to tell. While some data may be suggestive of ozone loss, no unequivocal signature of photochemical loss was determined during this mission. Considerable data analysis will be required before this question can be answered quantitatively. However, there was clear evidence during the mission that the stratosphere became photochemically primed for ozone destruction.

It should be noted that observing ozone depletion was not the primary goal of this mission. Even with significant perturbations to the chemical composition, ozone depletions much greater than 5 to 10% at ER-2 altitudes (up to 19 km) were not anticipated during the mission because vortex air is not generally exposed to adequate amounts of sunlight in January and early February. Interpretation of small changes in ozone is difficult and requires careful analysis of an ensemble of chemical and dynamical atmospheric data. Thus, the experiments focussed on studying the chemical and dynamical processes occurring in the Arctic stratosphere that set the stage for possible ozone depletion if the perturbed chemical composition is maintained in sunlight.

(2) Were PSC's observed and, if so, what information was obtained to describe and understand their formation?

Yes. PSC's were observed on many flights using particle spectrometers on the ER-2 and lidar instruments on the DC-8. In addition, PSC's were observed by the SAM II satellite instrument. The lidars indicated that both Type I and Type II PSC's occurred between 16 and 25 km, which is the altitude range for peak ozone concentration within the vortex. The ability of the DC-8 to penetrate farther into the Arctic vortex permitted an estimation of the geographical extent of the PSC's.

The distributions of PSC's with altitude, latitude, and longitude observed by the SAM II satellite instrument and the DC-8 lidars were consistent with theoretical predictions based on observed temperatures and assumed abundances of water vapor and HNO_3. Information on particle sizes and shapes and relative particle abundances were derived from lidar backscattering ratios at several wavelengths and from the extent of depolarization of the lidar beam. In situ particle spectrometers gave direct evidence of particle size distribution. Chemical composition data can be determined from wire impactor studies, and inferred from the particle size spectrometers and the ER-2 NO_y detector. Consistent with the lidar and SAM II measurements, the most commonly observed PSC's were thought to be Type I clouds containing HNO_3.

Nitric acid trihydrate (NAT), presumably a major component of Type I PSC's, forms at temperatures below 196K (-77C) at 50 mb pressure and abundances of H_2O and HNO_3 of 5 ppmv and 15 ppbv respectively. On a few occasions, the larger Type II water-ice PSC's which form at temperatures below 188K (-85C) were observed, especially on January 24, 31 and February 2. The consistency between the regions where PSC's were predicted to occur and where they were observed adds confidence in the above hypotheses regarding their chemical composition. The distribution of background sulfuric acid aerosols was also observed.

There are three conditions that are believed to contribute to the coid temperatures associated with formation of both types of PSC's. The first of these is the absence of sunlight during winter which leads to spatially extensive cold temperatures within the vortex. The second condition is one that arises due to large scale synoptic events in the troposphere which uplift and adiabatically cool large volumes of stratospheric air. For example, a large mass of Type II water-ice PSC's was observed on January 31 between 16 and 25 km. The presence of an underlying cirrus cloud having a top up to 14 km indicates that these PSC's were generated by vertical forcing due to a large-scale tropospheric weather system. Meteorological observations indicated that the volume of air that flowed through this PSC region was much larger than that which encompassed the PSC. Thus, a relatively small number of such events have the potential to process, and thereby perturb the chemistry of, a large portion of the Arctic stratosphere. The third condition involves the formation of lee wave disturbances within the stratosphere. Lee waves and their associated ice clouds (nacreous clouds) were observed to be persistent features in the Arctic stratosphere along the Scandinavian mountains. Lee waves form under strong flow conditions and can produce regions where temperatures are lowered 10°K or more below ambient levels.

Microwave temperature profiler measurements indicated that air parcels in the Arctic stratosphere experience temperature fluctuations on short timescales, i.e., 2°K within 10 minutes. The influence of such short timescale fluctuations needs to be investigated since they could be important in PSC formation mechanisms.

The lidar, SAM II, and in-situ observations have provided the essential data base upon which theories of PSC formation and heterogeneous chemical processing can be tested.

(3) Was the Arctic stratosphere found to be chemically perturbed?

Yes. There was strong evidence of significantly perturbed chemistry, particularly within the Arctic polar vortex. The following paragraphs compare our observations of the chemical composition of the Arctic stratosphere relative to that observed in Antarctica, recognizing that this mission was performed earlier in the season than was the Antarctic campaign. The observations are also compared to the predictions of current photochemical models that do not include the impact of PSC's on the chemistry.

Unless otherwise stated the in-situ measurements were made using ER-2 instrumentation at flight levels near 19 km and column measurements were made from the DC-8. It should be noted that, even at the highest ER-2 altitudes, measurements were being made near the base of the PSC clouds. Therefore, the DC-8 column and lidar measurements were vital in assessing the impact of the PSC's at altitudes above about 19 km. The abundances of a large number of the chemical constituents exhibited significant spatial and temporal variability because of the sampling of air with different histories.

The observed abundance of chlorine monoxide radicals (ClO) was significantly greater than that predicted by models not including PSC chemistry. Inside the vortex, ClO mixing ratios reached values as high as 800 pptv (parts per trillion by volume) in early February. These ClO abundances are similar to values observed previously in the Antarctic vortex. Outside the vortex, the observed ClO mixing ratios were normally 20 to 50 pptv, and, on one occasion, 100 pptv. The amount of ClO predicted by models without heterogeneous chemistry, at ER-2 flight altitudes, is about 10 to 20 pptv in full sunlight with negligible amounts at night. On several occasions north of the terminator (i.e., in the polar night) moderately high levels of ClO, reaching 100 pptv, were observed. Further, these were observed over a range of altitudes, indicating perturbed chemistry over an extensive vertical region. No ozone depletion is expected to occur in the polar night due to ClO since sunlight is required for ClO catalytic cycles to operate. Concentrations of ClO were variable, especially in January, due to the sampling of air with differing histories of sunlight, local solar zenith angle, cold temperatures, and chemical composition. In some instances, large increases in ClO abundances could be associated with air flow from regions where PSC's were believed to have been present within the past few days. These observations cannot be reconciled with currently understood gas phase photochemistry, but correspond broadly to model predictions involving the influence of polar stratospheric clouds.

Bromine monoxide radicals (BrO) were observed by an in-situ ER-2 instrument. Under sunlit conditions, mixing ratios between 2 and 8 pptv were found both inside and outside of the vortex, similar to the levels that were measured both in Antarctica and elsewhere around the globe. No BrO was detectable under polar night conditions. Column measurements of BrO from the DC-8 are in general agreement with these findings.

Elevated levels of chlorine dioxide (OClO), indicative of enhanced abundances of ClO in the presence of BrO, were observed both day and night. Daytime column abundances reached 0.1×10^{14} molecules cm^{-2}, while nighttime values ranged as high as 1×10^{14} molecules cm^{-2}. These values are broadly consistent with the ClO observations. They are only slightly lower than those observed in Antarctica and depend strongly on the level of NO_x and the history of exposure of the observed airmass to sunlight. Models not containing heterogeneous chemistry predict maximum column abundances of OClO to occur at night at a level of only about 0.02 to 0.05×10^{14} molecules cm^{-2}.

Column abundances of the inactive chlorine reservoir species, chlorine nitrate ($ClONO_2$), were elevated at the edge of the vortex, often reaching 3 x 10^{15} molecules cm^{-2}, but decreased towards the interior of the vortex. Predicted levels of $ClONO_2$ do not exceed 1 to 2 x 10^{15} molecules cm^{-2} in the absence of heterogeneous chemistry and do not vary significantly with latitude. These results are similar to those from Antarctica and suggest the conversion of inactive chlorine to another form at higher latitudes.

The ratio of the column abundance of hydrochloric acid (HCl) to that of hydrofluoric acid (HF) is a measure of the fraction of inorganic chlorine that resides in the HCl reservoir rather than in other forms. Models without heterogeneous chemistry predict values of this ratio ranging from 3 to 4 at high latitudes. The ratio observed during this mission is approximately 4 outside the vortex. Inside the vortex the HCl to HF ratio decreased to values ranging between 2.5 and 1. HCl to HF ratios as low as 0.7 were observed within the Antarctic vortex. These observations cannot be explained by current theory without chemical or physical conversion of HCl into other forms of chlorine at altitudes below about 25 km. The low values of the sum of HCl + $ClONO_2$ are strongly suggestive that a significant fraction of the total inorganic chlorine has been converted to more active forms, such as ClO, in agreement with the ER-2 observations of ClO.

Column abundances of HNO_3, often reaching 30 x 10^{15} molecules cm^{-2}, were much larger than those observed in Antarctica, especially within the polar vortices. This indicates that extensive denitrification of the Arctic vortex has not occurred at all altitudes even though the ER-2 NO_y measurements discussed below show significant denitrification at some altitudes.

Extremely low column abundances of nitrogen dioxide (NO_2) were observed in the Arctic atmosphere as compared to midlatitude values. Within the vortex, values were often less than 0.3 x 10^{15} molecules cm^{-2}, even less than observed in late winter / early spring in the Antarctic vortex. These observations are difficult to interpret even with models that incorporate heterogeneous chemistry and would require removal of NO_2 below altitudes of at least 30 km . Such removal processes could include repartitioning of reactive nitrogen species or denitrification (removal of NO_y).

The abundances of NO_y varied with latitude and altitude. Maximum values of about 15 ppbv were observed at ER-2 flight altitudes. While most of the early flights showed little (some was observed on January 16) or no evidence of denitrification, the flights on January 30 and February 7 & 8 showed significant depletion of NO_y (removal of approximately 90% of the NO_y reservoir), with residual values of NO_y as low as 1.5 to 2 ppbv. On at least one occasion denitrification was observed over a few kilometers of altitude. Models with heterogeneous (PSC) chemistry are necessary to account for denitrification. In-situ measurements of NO_y at the highest DC-8 altitudes (12 km) were occasionally elevated by as much as a factor of 3 to 4 on several flights late in the mission. This is possibly indicative of evaporation of particles containing nitric acid (HNO_3) precipitating from above.

Water vapor mixing ratios were essentially constant at approximately 5 ppmv. These ER-2 observations were confirmed by column measurements from the DC-8. Dehydration was limited in most denitrification events to a few tenths of a ppmv of H_2O at most. On February 7, ER-2 measurements showed possible dehydration over limited regions, with water vapor mixing ratios as low as 4.5 ppmv concurrent with denitrification (i.e., water loss of about 0.5 ppmv). Denitrification in Antarctica was observed on all flights within the vortex, with residual NO_y levels as low as 1.5 to 2 ppbv, and was always accompanied

by some level of dehydration, with measured water vapor levels as low as 2 ppmv (i.e., water loss of up to 2 to 3 ppmv).

(4) Was there evidence that the PSC's were responsible for the perturbed chemistry?

Yes. The combination of elevated levels of both ClO and OClO day and night, coupled with the observed variations in HNO_3, HCl, and $ClONO_2$ cannot be reconciled purely in terms of gas phase homogeneous chemistry, but appears consistent with the chemistry believed to take place on PSC's. In particular, peak ClO mixing ratios of between 400 and 800 pptv which were consistently observed in the sunlit portions of the vortex from January 30 onwards, and the persistent ClO abundances of 40 to 100 pptv measured on several flights well north of the terminator and inside the polar vortex, support this view. There were instances when, in relatively homogeneous air masses (as indicated by N_2O abundances which act as tracers of atmospheric motion), abrupt increases in ClO were observed. Those "edges" in ClO, which could not be attributed to changes in local solar zenith angles, may well be associated with the boundaries of exposure to PSC regions. Two factors make the coincidence between enhanced ClO and the edge of the PSC exposure extremely strong evidence that heterogeneous reactions on PSC's are responsible for the perturbations. These are (i) the demonstration in the laboratory that reactions such as HCl + $ClONO_2$ proceed rapidly on ice surfaces and (ii) the observed re-partitioning of chlorine and nitrogen containing species in the vortex from DC-8 column measurements. The highly depleted columns of HCl, the major chlorine reservoir species, can be explained by its conversion on PSC surfaces.

Although many of the large dramatic increases in observed ClO appear to be due heterogeneous chemistry occurring on PSC's, the possibility that background sulfate aerosols may also exert a slower, but more spatially extensive, influence on global ClO abundances cannot be ruled out.

(5) Was denitrification observed and, if so, are the processes understood?

Direct evidence of localized denitrification was observed by in situ ER-2 instruments on three occasions. However, the mechanisms involved are not adequately understood. The lack of significant dehydration during these events presents a contrast to the Antarctic observations. Denitrification and dehydration both are expected to occur through the sedimentation of aerosols grown by the deposition of nitric acid (a major part of the measured NO_y) and H_2O, respectively, on to pre-existing sulfate aerosols. The ER-2 measurements have confirmed the existence of NO_y-containing aerosols of the Type I category in the Arctic and Antarctic, but with sizes that sediment too slowly to effect denitrification. Bigger aerosols, tentatively identified as of the Type II category (largely water-ice) and large enough to fall rapidly, were observed during both the Arctic and Antarctic missions but their NO_y content has not been established. The DC-8 lidar measurements show PSC regions to be a mixture of both types with non-uniform horizontal and vertical distributions. The removal processes for NO_y and H_2O are also likely to be non-uniform, confined to small scale regions and require conditions favorable for both classes. Therefore, many of the physical processes responsible for denitrification are not fully understood.

Formation of PSC's containing water-ice requires lower temperatures than PSC's containing NO_y. Since these lower temperatures are much more common in the Antarctic than in the Arctic, it was important to learn if denitrification could occur only in conjunction with dehydration. As mentioned above, denitrification has been observed in the Arctic,

but little or no dehydration has been found. In contrast denitrification was persistently associated with dehydration in the Antarctic. The Antarctic observations, however, do not preclude the possibility that denitrification occurred without dehydration as an early phase of the removal process. One explanation for the Antarctic is that, after initial denitrification, further lowering of temperatures continues to form water ice thereby increasing the level of dehydration without further denitrification. Thus, the cold temperatures of the Antarctic may not be required in the Arctic.

The column abundances of HNO_3 are considerably elevated over a large volume of air within the vortex, indicating that large scale depletion of HNO_3 (the principal component of NO_y) has not occurred. This may indicate that the denitrification observed at ER-2 flight altitudes is either highly localized, both vertically and horizontally, or that the PSC's precipitate from ER-2 altitudes but evaporate at or above DC-8 flight altitudes. This is consistent with the observations of increased abundances of NO_y from the DC-8. The situation is clearly different from that in the Antarctic vortex where ER-2 NO_y and column HNO_3 measurements indicated extensive denitrification throughout the lower stratosphere.

(6) Has the spatial extent of the chemically perturbed region of the vortex been defined and is it understood?

The persistence of elevated ClO abundances on all ER-2 flights during the last half of the mission indicates that the chemical composition of most of the lower Arctic stratosphere within the vortex has been perturbed. Column abundance measurements support this view. In particular, the column abundances of HCl and other chlorine reservoir species have been reduced considerably over a large volume of air within the vortex, indicating large scale chemical and / or physical processing. The more extensive the region of perturbed chemistry, the greater the potential for ozone depletion in the northern hemisphere before and after the breakdown of the Arctic vortex.

One significant observation was the occurrence of high concentrations of ClO in the absence of concurrent denitrification. Clearly, while denitrification is not required to maintain elevated levels of ClO, removal of NO_x radicals is. The formation of Type I PSC's begins approximately 8°K above the frost point (depending on local conditions) and repartitions both chlorine and nitrogen species. This leads to elevated reactive chlorine (ClO) and reduced NO and NO_2 (by conversion into nitric acid). The lidar observations of extensive Type I PSC's provides an indication of the spatial extent over which this chemical repartitioning can occur.

On January 31, a large water-ice cloud (Type II PSC's) was formed by a single synoptic-scale tropospheric upwelling. The ice cloud extended across the vortex boundary influencing air both inside and outside the vortex. Air parcels that trajectory models indicated had been processed through this water-ice cloud later showed evidence of significant chemical transformations.

(7) Can the absence of large ozone depletion during the mission be reconciled with the observations of perturbed chemistry?

Yes. While high abundances of ClO have been observed in the vortex during sunlit hours, at night the abundance of ClO is reduced by conversion into its dimer form (Cl_2O_2). Both the reconversion of the dimer back to ClO and the chlorine catalyzed destruction of ozone require sunlight. Most of the vortex air was in the dark (in spite of excursions of some air

parcels to lower latitudes) and, therefore, the catalytic cycles for ozone destruction were relatively inefficient throughout this mission. The main ozone depletion in the Antarctic did not occur until later in the spring when solar radiation returned to the polar region. Thus this Arctic mission terminated at a time corresponding to mid-August in the Antarctic, i.e., before the seasonal formation of the Antarctic ozone hole. **The vortex air at the end of this mission was chemically perturbed, with increased abundances of ClO radicals, and as the amount of sunlight increases has the potential to destroy ozone at a significant rate.**

(8) Were the observed perturbations to the chemical composition of the Arctic stratosphere a result of atypical meteorological conditions this winter?

No. We cannot attribute the chemical perturbations that were observed during this mission to unusual meteorological conditions. The winds and temperatures in the Arctic stratosphere this winter were not markedly different from other years of this decade. The polar lower stratosphere was about one standard deviation colder in January 1989 than the long-term January mean. However, the critical parameters for stratospheric denitrification and dehydration are the local minima in temperature. The coldest 50 mb (about 19 km) temperatures and minimum lower stratospheric satellite temperatures (averaged over several km of altitude centered around 90 mb) for the northern polar hemisphere were lower than average, but this was not an extreme year from a temperature perspective. Thus the meteorological conditions which produce the PSC's should not be viewed as uncharacteristic.

Through January 1989, this winter's total abundance of PSC's, determined by the SAM II satellite instrument, is already slightly greater than the total winter average for the last ten years. February (at the time of this writing) is not over and if PSC occurrences in February are as frequent as in some past years, this entire winter will have been a very active PSC season compared with an average winter (but not outside the statistical range).

(9) What are the implications of the observed perturbed chemistry on future ozone levels this year at high northern latitudes?

The vortex air at the end of this mission was primed for ozone destruction, with abundances of ClO radicals as high as 800 pptv. Significant ozone loss can occur until the normal partitioning of chlorine species is reestablished. A major controlling factor in this process is the reintroduction of NO_x into the perturbed air parcels. This reintroduction can occur in two ways: the photolysis of HNO_3 or N_2O_5 and / or mixing with air containing normal levels of NO_x. Prior to vortex breakdown, which normally occurs in February, ozone destruction will be primarily limited by the first process and hence by the extent of denitrification. No extensive experimental campaigns are currently planned to follow the vortex breakdown. However, should the vortex persist for several weeks beyond the end of this mission, the ozone loss may be detectable by the Total Ozone Mapping Spectrometer aboard the Nimbus 7 satellite, the SAGE II instrument aboard the Earth Radiation Budget satellite, and the ozone-sonde and Dobson networks.

The level of ozone depletion at high northern latitudes after the breakdown of the polar vortex is difficult to quantify. Air parcels containing 800 pptv of ClO and about 5 pptv of BrO can destroy a significant fraction of the ozone within them over time-scales on the order of weeks if exposed to sufficient sunlight. To retain such high levels of ClO requires air parcels to remain depleted in NO_x. This condition depends on many chemical and dynamical factors including mixing with ambient air containing higher levels of NO_x, the possibility of further exposure to PSC's, the form and abundance of residual NO_y within

the air parcel, and the level of exposure to sunlight which dictates the photochemical loss and recovery. Chemical recovery and mixing timescales are both roughly on the order of weeks. Therefore, chemical and dynamical modeling studies are needed to quantify the impacts of such chemically perturbed air masses on ozone in the northern hemisphere.

(10) Can the observations of perturbed chemistry explain the high latitude winter ozone decreases reported by the International Ozone Trends Panel?

Until a comprehensive analysis of the data from this mission is accomplished and model calculations performed, this question cannot be addressed quantitatively. The International Ozone Trends Panel reported that the ozone column decreased by about 5 - 6% between 40° and 60°N since 1970 during the winter months. This decrease was over and above changes attributable to known natural variability and greater than that predicted by photochemical models that do not include heterogeneous chemistry. There is strong evidence that heterogeneous processes were important in increasing the abundances of ozone-destroying active chlorine in the Arctic during this mission.

(11) Have the results of this mission improved our understanding of the Antarctic ozone hole?

Yes. The experimental observations made during this mission have increased confidence in the interpretations applied to the Antarctic data and strongly support the significance of heterogeneous reactions in perturbing the chemical composition of the polar stratosphere. The importance of large scale dynamical forcing events for generating the cold temperatures required for PSC formation and subsequent chemical perturbations has been demonstrated during this mission as in Antarctica.

The lower stratosphere temperature record for the past 10 years shows that the warmest years in Antarctica are colder than the coldest years in the Arctic . Therefore, the observation during this mission of large chemical perturbations by Type I PSC's, which are formed at warmer temperatures than Type II PSC's, indicates that even in relatively warm years in Antarctica there would still be strong chemical perturbations.

(12) In the light of the results of this mission, is there a need to strengthen the regulatory provisions of the Montreal Protocol?

An answer to this question requires more than just scientific input. The photochemical models that were used as a basis for the Montreal Protocol negotiations did not include heterogeneous processes and hence underestimate ozone loss in or near both polar regions due to man-made chlorine and bromine containing chemicals. It is clear that even if the Montreal Protocol on Substances that Deplete the Ozone Layer is fully implemented as currently written, with worldwide participation, it will still allow the atmospheric abundance of chlorine and bromine to increase by about a factor of two by the middle of the next century. Therefore, based on our current understanding, such continued build-up of man-made chlorine and bromine chemicals is expected to lead to additional ozone loss in the Arctic and Antarctic regions. Even with a complete phase out of the fully halogenated CFCs, full recovery of the ozone layer will take many decades to centuries given the long atmospheric residence times of the CFCs .

(13) When will the data be in a form suitable for use in formulating national and international regulatory policies?

The schedule for the assimilation and publication of the results is brisk. Short letter publications by individuals and groups of scientists who are part of this mission will be submitted for peer review by September, 1989. More comprehensive analyses of the data will continue for at least an additional year resulting in further scientific papers. After these analyses, the data from this mission will be made available to the international scientific community. The published works will represent the best basis for any possible policy reevaluations. A scientific assessment is currently being prepared by the international scientific community under the review provisions of the Montreal Protocol . This assessment is scheduled for completion in August 1989, will include a portion of the results from this mission, and will serve as input to the 1990 policy review of the Montreal Protocol.

QUESTIONS OF THE COMMITTEE AND THE ANSWERS THERETO

Question 1: The Montreal Protocol set up a mechanism for periodic scientific reassessment of global ozone depletion. How well is the ongoing reassessment proceeding?

Answer 1: The reassessment is going very well. The first international assessment, required by January 1990 under the terms of the Montreal Protocol, is already underway and should be completed by the end of August 1989. The scope of the assessment has been determined, the participants have been selected, the chairmen have been chosen, and the schedule for writing and reviewing the document has been established.

Question 2: Given your experience as a participant in the negotiations that led to the original Protocol, do you think that the new evidence of increased ozone depletion will lead to amendments to the Protocol requiring faster, larger cuts in CFC production?

Answer 2: Since the Montreal Protocol was signed in September 1987, there have been three key scientific findings demonstrating that CFCs decrease ozone more than previously thought:

(1) The weight of scientific evidence strongly indicates that man-made chlorine- and bromine-containing substances are primarily responsible for the observed decrease in spring-time Antarctic ozone within the polar vortex.

(2) Analysis of data from ground-based "Dobson" instruments, after allowing for the effects of natural geophysical variability (solar cycle and the quasi-biennial oscillation [QBO]), show measurable decreases in the annual average of total global ozone from 1969 to 1986 ranging from 1.3% to 3.0% between 30-60 degrees in the Northern hemisphere. This decrease may be roughly two times larger than those predicted by photochemical models. Unfortunately, the short time period of the study and the small network of Dobson instruments make it very difficult to estimate how these changes relate to long-term natural global ozone fluctuations.

(3) The preliminary results of the recent expedition to Norway demonstrate that enhancements of ozone-depleting chlorine-containing substances do indeed occur in both the Arctic and Antarctic stratosphere, and represent an additional ozone-depleting process that was not included in the stratospheric ozone assessment models used as a basis for the Montreal Protocol.

It should also be noted that after recalibration of the Total Ozone Mapping Spectrometer (TOMS) aboard the Nimbus 7 satellite, a decrease in total column ozone of 2.5% "globally" (53 N to 53 S) was reported between October 1978 and October 1985. However, because of the shortness of the data record (less than one full solar cycle), it is not possible to unambiguously separate out the contribution due to natural variability (changes in solar output)

from that due to human activities (build-up of CFCs in the atmosphere).

All of these findings would need too be taken into account when considering amendments to the Protocol.

Question 3: The Montreal Protocol was the result of scientists and policymakers listening carefully to one another. This doesn't always happen. Why did it happen in this case?

Answer 3: Often the scientific community produces a number of sometimes conflicting statements, making effective policy determination and implementation difficult. However, in this case the essential ingredient was a unified international scientific assessment, and therefore only one scientific statement about the nature of the problem. This scientific assessment was based upon a strong research effort, particularly in the U.S. Also in this particular case, a number of scientists were able to communicate their perceptions of the problem and potential solutions in language that the policymakers could understand.

Question 4: I understand that the Chemical Manufacturers of America provided research funding for both the Arctic and the Antarctic ozone expeditions. Has CMA shown a long-term commitment to funding research to address environmental issues? Do you feel that their financial participation in the process in any way compromises the credibility of the scientific findings?

Answer 4: The CMA has a special panel for CFC research called the Fluorocarbon Program Panel comprised of nineteen producer companies from North America, Europe, Japan, and Australia. This panel only conducts scientific research, not advocacy. They have contributed about one and a half million dollars each year for the past fifteen years toward CFC research.

We do not feel that CMA's financial participation in any way compromises the credibility of their research. The scientific research of the Panel is beyond reproach. The Panel funds scientists from the best universities around the world, including U.S. scientists that NASA and the NSF would otherwise fund. The Panel's peer review process for proposals is similar to that of NASA's. The Panel does not censor scientific findings, and their publishing standards meet or exceed those found in other respectable scientific institutions. Their advisors have included Nobel prize winners such as Dudley Hershbach. The CMA funding is extremely important to CFC research since it funds much of the non-U.S. component of international activities, which NASA cannot do.

Question 5: I noticed that the Arctic Ozone Expedition did not receive funding from EPA, the agency responsible for regulating CFC production. Why is that? In general, how important is it that the science be independent of policy?

Answer 5: Funding was not requested from EPA. NASA and NOAA have a congressional mandate and the funding to study the physical and Chemical processes that control atmospheric ozone. EPA has

primary responsibility for policymaking, and for monitoring how human health and ecosystems will respond to changes in the ozone.

It is extremely important for science to remain independent of policy. Scientific research and data must be viewed to be above reproach and totally uncompromised. Science agencies need longer time horizons for planning and implementing scientific programs than the day-to-day needs of policy often allow. This can be most easily accomplished through a clean separation of policy and science. Indeed, the reason that NASA, in collaboration with NOAA and NSF, could study polar ozone so rapidly and effectively was the commitment of the U.S. government to a comprehensive, long-term research program. It is expected that this collaboration be even further strengthened through the interagency research planning efforts of the Committee on Earth Sciences.

Question 6: As we phase down CFC production we need to make sure that the chemicals we use to replace CFCs are environmentally safe. The United States presently produces millions of pounds of CFCs annually, so in the future we will clearly have to produce millions of pounds of CFC replacements. How confident are we that the CFC replacements now being tested will not cause environmental damage when released into the atmosphere? What kind of research is needed to make sure these replacements do not cause more environmental damage than the CFCs they replace? How long would such research take?

Answer 6: The scientific community is critically analyzing the environmental impacts of all known potential substitutes. Industry (through the Alternative Fluorocarbons Environmental Acceptability study) and government science agencies are currently collaborating on the problem, analyzing substitutes for their impacts on tropospheric and stratospheric ozone, global warming, acid precipitation, human health, etc. A critical assessment will be available by mid-May when Dr. Robert Watson will chair an international review of the evaluation of potential environmental damage by CFC substitutes.

While there is a reasonable scientific data base concerning some aspects of the potential substitutes, there are clearly some scientific uncertainties associated with the potential environmental impact of CFC substitutes. The scientific community needs to perform additional detailed laboratory studies to determine how quickly these substitutes will deteriorate in the troposphere and what the optical properties are that could lead to greenhouse warming.

With the exception of toxological testing, most of the important data related to the environmental impacts of CFC substitutes could be obtained within a year or so.

Responses to Written Questions Submitted by Chairman Gore.

Question 1: Does the observed [ozone] depletion at 19-20 km at many latitudes in any way support the hypothesis that heterogeneous chemistry may be taking place in the so-called "aerosol layer" of the ozone layer? What is the magnitude and timing of all of NASA's efforts to resolve this issue?

Answer 1: It is possible that heterogeneous chemistry may be taking place in the "aerosol layer." NASA is currently conducting laboratory, field, and theoretical efforts to understand this issue. We continue to monitor ozone through satellite observations, and are aggressively performing laboratory studies of heterogeneous processes to attempt to simulate the potential impacts of those processes using the best theoretical models. In the next year or so, we plan to conduct aircraft observations at the mid-latitudes, in the same manner as in the Antarctic and Arctic campaigns, to determine if there is any direct evidence of the mid-latitude aerosol layer actually causing reductions in atmospheric ozone.

Responses to Written Questions Submitted by Senator Kasten.

Question 1: I understand that with respect to the CFCs, which are the general classification of the substances which cause ozone depletion, that there are some which are much more damaging than others. Also, I understand that there are other substances, which are not CFCs, which have been found to contribute to the problem. As we look toward developing policies on the use of ozone depleting substances, could you comment on whether there are some CFCs which are more damaging than others and whether there are other substances beyond the CFCs on which we should begin to focus?

Answer 1: The most damaging CFCs are the fully halogenated CFCs: those that contain carbon, chlorine, and fluorine but no hydrogen. These chemicals have atmospheric lifetimes of approximately one hundred years. Fully halogenated CFCs are used as refrigerants, foam blowing agents, and solvents. Other chemicals that contribute to ozone destruction are the halons, those bromine-containing substances used as fire retardants.

The Vienna Convention on ozone depletion noted that carbon dioxide, methane, and nitrous oxide all control atmospheric ozone. Increases in carbon dioxide and methane will increase atmospheric ozone, whereas increases in nitrous oxide will lead to ozone depletion. However, it is important to note that methane increases ozone levels in the troposphere near the ground. High ozone levels near the ground are toxic to human health, and will contribute to global warming.

Industry is planning to replace fully halogenated CFCs with partially halogenated CFCs, ones that will either contain hydrogen or will not contain chlorine. The CFCs with chlorine and hydrogen have short atmospheric lifetimes, so that large concentrations of chlorine cannot accumulate in the atmosphere. These hydrogen- and chlorine-containing substances will be ten to fifty times less effective in destroying the ozone (i.e., cause much less damage) than the CFCs they will replace. Therefore, to best limit the damage already done to the ozone layer, the regulations on fully halogenated CFCs currently included in the Montreal Protocol need to be strengthened, calling for close to a complete phase out on use of those molecules. These regulations would also need to include restrictions on the use of carbon tetrachloride, methylchloroform, and other chlorine-containing chemicals.

It must be noted that while there is a clear need to study the atmospheric and environmental impacts of gases such as carbon dioxide, methane, and nitrous oxide, the regulation of these substances is more difficult than regulation of CFCs because they are used and produced in agriculture and energy-related activities. These gases all contribute to the predicted global warming.

Senator GORE. Thank you all very much.

I thought we would do the 10 minute rule; Senator Kerry and I will start off, if you will put the clock on there.

Let me see if I can understand what you are saying in somewhat simpler terms. The chemicals called chlorofluorocarbons, which are used in all kinds of things, slowly work their way up to the stratosphere. And how high is the stratosphere? Where does it begin?

Dr. SOLOMON. About 12 kilometers or 16.

Senator GORE. Twelve to 16 kilometers; there is a band, is that right?

Dr. SOLOMON. Depending on latitude, the level at which you would encounter the stratosphere in the tropics is about 16 kilometers and at higher latitudes it is a little lower, but it is on that order. Call it 15.

Senator GORE. Eight or 10 miles, can we say that?

Dr. SOLOMON. Sure.

Senator GORE. Eight or 10 miles up, slowly these molecules work their way up, over a period of years, and even decades, correct.

Dr. SOLOMON. Yes.

Senator GORE. All right, now, let us stay away from the poles for a minute. Just in the normal atmosphere above Washington, D.C., these chemicals can destroy the ozone layer which filters out ultraviolet radiation, correct, before we even get to the poles, they can destroy ozone through a process that was predicted 15 years ago, correct?

Dr. WATSON. Yes, that is the Rowland-Molina theory, and we have tried to do calculations to see exactly what level of ozone depletion that would lead to. If our assumption, a ratified Montreal Protocol, is actually the equivalent of more of a global freeze and not a cutback, so eventually the amount of chlorine in the atmosphere goes from three parts per billion today, to six to nine parts per billion, we would expect that globally the ozone would deplete between 1 and 5 percent, which would mean that over Washington, D.C., it might be on the order of 2 to 3 percent, over the next few decades.

Senator GORE. All right, now, the Montreal Protocol was based largely upon the science that predicted this first destructive method, correct?

Dr. WATSON. Yes.

Senator GORE. And when you predicted out what would happen, you got to those numbers?

Dr. SOLOMON. That is right.

Senator GORE. Now, after the negotiations began after the public concern was generated, then you discovered a brand new method by which chlorofluorocarbons destroy ozone.

Now, first, in the Antarctic, when you found the hole in the ozone, and now, in the Arctic, what happens is that there are three things that are different at the poles.

Number one, it is much, much colder and that is important because that allows the formation of polar stratospheric clouds?

Dr. SOLOMON. Right.

Senator GORE. Is that the reason that temperature is so important?

Dr. SOLOMON. Yes.

Senator GORE. All right. Now, what is unique about those clouds is not only that they are cold, but that they are very high, eight or 10 miles up, correct?

Why do polar stratospheric clouds occur?

Dr. SOLOMON. I think the main point is that the stratosphere is extremely dry. It is much drier than the troposphere.

Senator GORE. Right.

Dr. SOLOMON. So unlike the troposphere, where clouds can form all over the place, in the stratosphere, one has to get extremely cold before clouds can form.

Senator GORE. Why?

Dr. SOLOMON. Condensation is going to be related to how cold the temperatures get. If it is extremely dry, you just have to get that much colder before you are going to get condensation.

Senator GORE. So at the—oh, excuse me, go ahead.

Dr. TUCK. There is something else in the stratosphere. In the troposphere when you talk about clouds, you are talking about water vapor and that is it.

In the stratosphere you are not. Photochemistry in the stratosphere produces nitric acid as well, and the presence of the nitric acid, together with the water, produces a mechanism where you can produce clouds at temperatures about five or six degrees warmer than if you just had straight water there.

Senator GORE. All right, now, at the poles, you then have these very high stratospheric clouds that do not occur elsewhere in the world.

Dr. SOLOMON. Yes.

Senator GORE. Now, that is important, because these chlorofluorocarbons destroy the ozone in two ways you found out. One reaction occurs just in the air, and that takes place slowly. But when you have the clouds, then they can interact on the surface of the ice crystals, is that correct?

Dr. WATSON. What the ice crystals do is they convert a form of chlorine, hydrochloric acid, which is unreactive to ozone, into the form of ClO which is reactive to ozone.

So, in other words, the clouds themselves, convert one form of chlorine that cannot react to ozone to another form of chlorine that can.

That is the importance of the clouds.

Senator GORE. Okay, when you first started worrying about ozone destruction, you did not take these stratospheric clouds into account at all?

Dr. WATSON. Correct.

Senator GORE. And you assumed that the way that the CFC's would destroy the ozone was the way it was predicted 15 years ago, in the atmosphere, in the absence of clouds.

Now, you have found out that where you have stratospheric clouds, at the poles, then because the clouds are there and the chemicals are interacting with each other inside these clouds, the destructive reaction takes place much more rapidly, correct?

Dr. SOLOMON. Yes, that is correct.

Senator GORE. All right, now, the second thing that is different—first of all in Antarctica—is that you have this vortex which is

quite stable over long periods of time, like the whirlpool in the bathtub when it drains, is that basically right?

Dr. SOLOMON. Yes, absolutely.

Senator GORE. All right, now, what that does is that it contains a little bowl within which this reaction in the clouds is uninterrupted by influxes of fresh air from the rest of the world, correct?

And so long as it is held in this little vortex, or bowl, the reaction speeds up, because these other chemicals that normally slow it down are destroyed, they fall out, and so, inside that bowl with the presence of clouds it speeds up rapidly.

Am I right so far?

[The witnesses all nodded, yes.]

Senator GORE. Okay, now, in Antarctica it takes place in our fall or the springtime down there, because that is the time of the year when you are just leaving the dark winter when the temperatures are coldest, yet the sun has risen and is providing light to induce the chemical reaction but is not yet providing enough heat to reduce the temperature and dissipate the clouds.

Is that why it takes place at that time?

Dr. SOLOMON. Yes, that is correct.

Senator GORE. Now, in the Arctic there are differences. It is not quite as cold, correct, so you do not get quite as many clouds?

Dr. SOLOMON. Yes.

Senator GORE. You were reluctant to assent to that.

Dr. SOLOMON. I think you can say on the basis of the satellite data that clearly there are fewer clouds in the Arctic than there are in the Antarctic.

A big question, I think, in all of our minds is whether or not a few clouds is enough. But, in any case, you are quite correct, Mr. Senator. There are fewer clouds in the Arctic.

Senator GORE. All right. Now, secondly, this vortex is not as strong in the Arctic. The Antarctic is land surrounded by ocean. The Arctic is ocean surrounded by land and partly for that reason you have a weaker vortex, and it wanders around. It does not stay in one place and occasionally it breaks up. Is that correct?

Dr. TUCK. That is broadly correct.

Senator GORE. So, the little bowl in which this reaction takes place does not stay tightly in place for as long and so periodically the reaction is interrupted by influxes of fresh air from outside the vortex, is that right?

Dr. SOLOMON. It is a leaky bowl. That is right.

Senator GORE. Still, when the sun comes and the sun rises above the horizon at the North Pole when March——

Dr. TUCK. March 23rd.

Senator GORE. You went before the sun came up?

Dr. TUCK. Yes.

Senator GORE. Why?

Dr. TUCK. The reason was after Antarctica, where we had actually seen PSCs early in the mission, but mostly what we saw was all the chemistry connected with the ClO destroying the ozone, during the last four weeks of the mission, anyway.

The big questions we had from Antarctica were how exactly do the PSCs work and can they do it in the Arctic. We already knew from satellite data from Pat McCormick's stuff at NASA Langley

that out of the last 11 winters there had been ten where PSCs had actually been detected in the Arctic. So, the natural question to ask was if the PSCs are in the Arctic, can they set up the chemistry to do any damage?

So, the reason we went was not to say yes, we can see ozone loss in the Arctic just the way we could in Antarctica. That would not have told us much scientifically, and as we have emphasized, all our expectations were that that would be a far more difficult signal to detect and, indeed, it is going to be.

But what we did succeed in doing was coming up with a very important result, and that was that the perspective we came away with from Antarctica was that in order to denitrify—and denitrification is the process that sets up the chlorine chemistry—the perspective we had in Antarctica was that everywhere where we saw denitrification, we also saw dehydration. The water vapor was very low.

Our belief was that the way you denitrified was to carry out the nitrogen on falling ice crystals. In other words, you had to reach temperatures that were five or six degrees colder than you need for the nitric acid, mixed nitric acid water clouds. You had to go all the way to ice clouds.

That five or six degrees is very important because it does not happen nearly as frequently in the Arctic to drop the temperatures down to the frost point.

Now, when we got to the Arctic what we found was that you can apparently get denitrification without very extensive dehydration. In other words, there was a difference to Antarctica. We were seeing denitrification without the occurrence of intense obvious dehydration, and that is a very important result.

We do not completely understand it yet, but nevertheless it is important. And that is why we went, to understand the PSC process better, and I think that is what we have done.

Senator GORE. Now, do you still need the sunlight to catalyze and create the reaction? You do, do you not?

Dr. TUCK. Unequivocally, yes.

Senator GORE. So, what you were looking for is the chemical reaction which creates the precursor of ozone destruction?

Dr. TUCK. Yes.

Senator GORE. And you were looking for the process that you found in the Antarctic by which the CFCs were broken down into chlorine monoxide?

Dr. TUCK. We have extended our understanding of the chain. What we saw in Antarctica was some PSC processing, but mainly, on almost every flight, we saw the results of it. We saw dehydration, we saw denitrification, and as the mission developed over the six weeks we were there we saw the ozone loss.

What we have done here is to extend backwards. We saw the PSCs starting to occur, and we saw the ClO being produced, we saw the HCl being lost, and all the signatures—it reinforced our picture that the PSCs were indeed doing to the homogeneous gas phase chemical balance what we thought they were doing.

Senator GORE. Now, did you leave the Arctic more concerned than you were when you arrived?

Dr. TUCK. Yes.

Senator GORE. Dr. Watson?

Dr. WATSON. I think you could say that about—not only about the three of us here, but probably all the 150 people that were in Norway.

Senator GORE. Substantially more concerned?

Dr. WATSON. Yes, I think we all expected to see perturbed chemistry. I think we were surprised that the chemistry was as perturbed, that the concentration of ClO was as elevated with the potential for ozone destruction.

Senator GORE. And what you said earlier is that given the fact you have discovered this more rapid rate of destruction and given that this international treaty was signed when we thought the destruction was taking place much more slowly from a scientific standpoint, now, what has been agreed to is not adequate to prevent the kind of damage that is going to take place, correct?

Dr. TUCK. Yes. It is absolutely clear that the regulations of the Montreal Protocol will not lead to adequate protection of ozone in Antarctica and almost certainly not lead to adequate protection of ozone in the Arctic.

Senator GORE. All right. I am going to come back to these questions later.

Senator Kerry.

Senator KERRY. Thank you, Mr. Chairman.

Doctors, the initial model created by Sherwood Rowland and Mario Molina estimated a certain rate of destruction of the ozone layer by virtue of the level of CFCs being emitted at that time. I think they were predicting damages as per either the 1990s or the turn of the century, I forget which. But, clearly that model proved inadequate, correct, and the rate of destruction that was taking place much faster than they estimated?

Dr. TUCK. The model has actually been through many gyrations since the early 1970s. We went at one stage from predicting global ozone losses as low as 7 percent to as high as 18 percent almost to nothing.

What we are saying here is that over the last few years the models that we used for the Montreal Protocol are clearly missing processes such as those induced by the PSCs that can lead to ozone destructions. But since Sherry Rowland and Mario Molina came up with that theory, there have been many, many changes in our understanding.

Senator KERRY. Is there a message for us as policy makers as a result of that underestimating and the evidence which is now clear—based on the revisions of those early models added to the recent findings that you have of these some one hundred people unanimously coming back from the Arctic expedition. Does that message to us as policy makers go beyond merely saying the Montreal protocol is not adequate?

Dr. TUCK. I think that is basically the message. If, indeed, we want to protect atmospheric ozone, especially in the polar regions, the message is that we are much more concerned than when we went to Norway or before we went to Punta Arenas and the regulations under the Montreal Protocol do not provide adequate protection for ozone in the stratosphere, especially in the polar regions.

Senator KERRY. Now, let us try to quantify that concern a little bit in a way that the layperson can understand it. I mean, you say as a scientist you are concerned. You are concerned about these two areas. What about the problem of tropospheric ozone? Leave aside what is happening in the stratosphere and the Arctic and Antarctic. What is the meaning in terms of the increase in tropospheric ozone if that were allowed to continue at its current rate? Can you quantify that in simple straightforward terms?

Dr. TUCK. Obviously there are several of man's activities leading to increases in non-methane hydrocarbons, methane itself, oxides of nitrogen, all of these lead to an increase of ozone in the troposphere.

This has two reasons to be detrimental. The first is ozone in the troposphere can act as a greenhouse gas, just like carbon dioxide, methane, nitrous oxide and the fluorocarbons. Hence, we would predict some change in the thermal balance of the troposphere because of the increase of ozone, potentially global warming.

Second, ozone at ground level is known to have potentially harmful effects to both terrestrial ecosystems and to human health.

Senator KERRY. Now, let's talk some more about damage to stratospheric ozone in the Antarctic. Would you try to quantify that in, again, layperson's terms? What is the impact on the average person's life of that continuing damage?

Dr. TUCK. In my opinion, the concern for the Antarctic is we are conducting an experiment where we have changed a major part of the natural environment, though not many people live in Antarctica, therefore, one cannot be concerned primarily with impact of increase UV, ultraviolet radiation, on people in Antarctica.

However, what we cannot quantify is what the increased ultraviolet radiation over Antarctica will do to the fish populations and the krill in and around Antarctica. I think the question is much simpler. Do we want to see a major perturbation to our environment such as a monstrous change in the ozone over Antarctica. We do not know whether there will be any effects or no effects on the climate system.

We have significantly changed ozone over Antarctica. It can clearly lead to a change in the temperature structure of Antarctica. We do not know whether there will or will not be changes to the climate system of the earth. Therefore, I think it is the uncertainty of what the impact is that has some of us concerned.

Senator KERRY. Is it possible to go beyond that yet in terms of the science? I noted, Dr. Tuck, that you said that you cannot predict what will happen with confidence. I was struck by that.

Can you predict without confidence? Can you set out a series of worst case scenarios of what you envision even though you cannot be certain?

Dr. TUCK. Well, as I said, if you are asking for advice from scientists on policy questions, I will just preface it by saying that I can give a scientific input, but obviously there are a lot of other things that go into policy questions, that my opinion is no more valid on than anybody else's. So, I will just give you the view of a scientist.

The system we are dealing with is nonlinear. Now, the simple homely analogy is the stock market crash of a couple of years ago.

It comes quickly out of a base line fluctuation and grows rapidly in amplitude to something that is visible to everybody.

And that is rather the way the Antarctic ozone hole started. And, as I said, we are dealing with a system that is fundamentally nonlinear. And if you take—you can ask the simple question, did we predict the Antarctic ozone hole either on chemical grounds or on meteorological ones, and the answer is no, we did not.

If you look at weather forecasting models, they run out of skill after about five to seven days, something like that. And we—as I said, we did not predict the Antarctic ozone hole.

There is a lot of hard and very good work and there has been tremendous progress made in the last 10 or 15 years in our ability to calculate the behavior of the system and certainly there has been a lot of effort put into calculating very average states in the future. But, when you cannot predict—when you cannot calculate accurately all aspects of the present system, it is very difficult, given that it is nonlinear and can give you surprises, it is very difficult to believe that you can calculate the perturbations with confidence.

Now, having said that, then the only sensible attitude, since it is nonlinear—and the system has demonstrated it is capable of surprising us—I think it is prudent to err on the side of caution.

Senator KERRY. Now, there is evidence that the increased ultraviolet rays as a result of the depletion of ozone, at least in the Antarctic, may be having an impact on the phytoplankton and krill and so forth. There are linkages between those systems.

Where is our research at this point in time? I understand we do not yet even have a benchmark of the density of that food supply in the region. Is that true?

Dr. TUCK. With your permission, I would like to pass that one to Dr. Watson.

Dr. WATSON. As I understand it, because actually bad policies of not adequately funding research in the area of impacts, I would have to say our knowledge is extremely poor and not only in the Antarctic system, but also throughout the world. A significant amount of money has been spent on understanding the physical chemical system. It has resulted in campaigns such as this where we have brought you, I think, rather interesting and solid results rather quickly.

However, the same cannot be said about the level of funding for trying to understand the impacts for ozone depletion. This country, nor any other country in the world, has put adequate funding into that area. So, you are absolutely correct, there is no good base line, and one would have to say we are in a state of ignorance.

Senator GORE. Would the Senator yield on that question?

I recently explored this, and the only scientific study in the world to establish a base line on the populations of phytoplankton in a given area of the Antarctic Ocean is a prelude to an intensive study of what increased UV radiation would do to those populations. It is taking place right off of Palmer Station in the Antarctic Peninsula, and unfortunately, all of that data has apparently just been wiped out by the oil spill which took place there, and they believe they have lost two years' worth of work, and there is no

other comparable study that the NSF knew about anywhere in the world. Excuse me.

Senator KERRY. I appreciate that comment, and I was going to underscore that by saying that for the last eight years, NOAA's research budget in this particular area has been cut.

I asked the question clearly as a way of trying to highlight the fact and your answer highlights it and your comment, Senator Gore, also highlights it. If we are going to be talking about major reductions in CFC emissions, with impacts on industry, and competitive impacts due to possible unilateral steps, to not have this kind of bench mark and to not have an understanding of what the impacts are in the short and long term is clearly negligent in the worst sense, and I hope we are going to try to rectify that to a degree this year.

Let me ask with respect to the science now—since we are going to be sitting here debating where the priorities are going to go in that science—Dr. Watson, you mentioned the importance of understanding the increases in carbon tetrachloride and in the methyl chloride levels now in dealing with the ozone problems.

Can you prioritize for us? Maybe that is dangerous, but I would like to ask you if you could or would be willing to. Where do you think the most important immediate impact studies ought to take place, and how we ought to be approaching that. For instance, what do we need to know about carbon tetrachloride?

Dr. WATSON. With respect to carbon tetrachloride, I think the key issue here is a simple one. Which countries in the world are releasing carbon tetrachloride to the atmosphere?

I do not believe it is primarily the United States or Europe. The indications are it is coming from the Eastern bloc countries, but they are poor indications. We need to understand where it is coming out. That is more doing an inventory of where the gases are released.

In general I think there are many areas in stratospheric research that need to be understood. Are the background aerosols primarily put into the atmosphere by volcanic action playing a role in changing ozone that was hitherto not understood?

We need to have a much better monitoring system of not only the atmosphere but the entire globe. We need a base line to understand what changes are occurring, what is natural variability and what might conceivably be due to human activity. As I will not, unfortunately, give you the answer you want.

I believe that the nation must engage on a solid campaign of doing global research where you look at the land, the atmosphere and the ocean all at once. Now, within that you can clearly prioritize small elements.

I believe, fortunately, in the stratospheric ozone issue we have indeed a solid effort on looking at the physics and chemistry. We need a base line, a bench mark of how quickly it is changing, and we also need to look quite carefully at what the impacts of ultraviolet radiation on both natural ecosystems and well as managed ecosystems. And, unfortunately, our knowledge base is quite poor at the moment.

Senator KERRY. I see that my time has expired and Senator McCain is here, so I will wait for another round.

Senator GORE. We will have a second round.

We are happy to welcome a member of the full committee, Senator McCain.

Senator MCCAIN. Thank you, Mr. Chairman. I thank the witnesses for their very important and compelling testimony. I just have one question for the witnesses, and that is what effect on the overall ozone layer does the depletion of the ozone layer over the Antarctic mean in your view?

Dr. TUCK. If you take the amount of ozone or if you take the vortex in Antarctica at the middle of October or end of October and take that volume of air that is depleted in ozone, it is clearly and detectably depleted in ozone, and if you simply dilute that by mixing, which is what happens with the rest of the stratosphere in the Southern Hemisphere, you get an effect, obviously, but it is a fairly small effect.

There is a further question, though, and that is are you indeed dealing with a contained air mass or is the bucket leaky, and this has already been alluded to in the previous testimony.

And the extent to which that bucket leaks could be important, and it is controversial. We are still working on it. We do not know the answers.

But if the thing is a continuous process or with some mass flowing through it and it is spitting out air to mid latitudes, it has got less ozone in it than it otherwise would have had, then that is a very different question than just a once and for all, a once only dilution. And we simply do not know the answer to that yet. It is controversial. Different people have got different views.

Dr. WATSON. I think that the point is that we would not expect massive ozone depletion at other latitudes in the Southern Hemisphere, but there could well be an impact on the order of a few percent which indeed would still be significant.

As we all know, the relationship has been said here today, a 1 percent decrease in ozone could lead to an increase in the number of white-skinned people with non-melanoma skin cancer, between 3 and 4 percent. So, even if there is only a few percent change over Australia and New Zealand, that could indeed be significant for the increase in the number of people getting non-melanoma skin cancer.

Senator MCCAIN. Dr. Solomon.

Dr. SOLOMON. I guess the only thing I would like to add is to underscore one of the things that Dr. Watson alluded to a few minutes ago. I think we have to be concerned not only about what is happening in polar regions, but also about our inability to predict what might happen at lower latitudes.

It is not only polar stratospheric clouds we need to worry about. We need to worry about other forms of aerosols, other forms of particulate matter that exist naturally throughout the atmosphere.

There are fewer of them certainly than what you have in a cloud, but they are still there and they could have a very pronounced effect on the ozone depletion that you would get even locally over any part of the atmosphere.

Senator MCCAIN. Is there a degree of concern being displayed by other western nations in your view as there is in this country?

Dr. WATSON. In my opinion, the answer is yes. I followed the Vienna Convention for the Protection of Ozone and the Montreal Protocol quite closely, being at most of the meetings.

I think there has been a significant change of opinion. I was at a meeting in Great Britain only a few weeks ago and Virginia Bottomly, who is one of the deputy environment ministers, stressed quite strongly, as did her boss, Mr. Ridley, that there should indeed be a complete phaseout of fully halogenated CFCs.

This, as I understand it, is the British position. I think it will be announced once again by Margaret Thatcher at the meeting on March the 5th and 6th, and so for a country like Britain, that at one stage was less concerned than the United States about CFCs, I would have to say at the moment they seem quite concerned.

Other countries in Europe such as Holland, countries such as Denmark have for the last ten years been extremely concerned about this issue. So, I do see a tendency in Europe to have a concern.

I should also point out——

Senator MCCAIN. Could I interrupt you? Do you also see that concern in eastern Europe? You mentioned that a lot of the problem seems to be emanating from there.

Dr. WATSON. I cannot honestly answer that question. Certainly the Soviet Union was a very strong and active participant in the Montreal negotiations, but on their current view is of whether we need to go beyond the Montreal Protocol, I cannot comment.

All I can comment on, in addition to government seeming quite concerned, is many industries that produce CFCs have indeed called for a phaseout of CFCs. So, I see a movement in the direction on the part of large producer industries and several governments to move well beyond the Montreal Protocol.

Senator MCCAIN. Thank you. Thank you very much, Mr. Chairman.

Senator GORE. Thank you.

Let me come back to some of the basics of this. Let me follow up on what Senator McCain was asking.

You talked about the findings of ozone depletion in the mid latitudes, Dr. Watson, basically in the latitudes that cover the United States and western Europe. And you said in winter it is now 5 to 7 percent less than it was ten years ago?

Dr. WATSON. 1970, so 17 years ago.

Senator GORE. Less than it was 17 years ago. What about in summertime?

Dr. WATSON. I would have to say the information is ambiguous. There is not a clear signal. I have got the data in front of me and between 30 and 39 degrees north, typical of Central North America here, it says that we had a 1.9 percent decrease with a standard deviation of 0.8. So, it is just significant to the two and a half to three standard at three sigma deviation.

I would say there is evidence of an ozone loss but it is not such hard evidence as what we have in the wintertime period, between 40 and 60 north.

You would also to put it in perspective, we only predict somewhere between a half and a 1 percent change, so there is a consistency between the theory and the observation, and ozone, as we

both know, is extremely variable in the atmosphere. So, if, indeed, the ozone has changed that 1 to 2 percent, it is a very, very tough thing to detect unambiguously. When a signal gets to 5 to 10 percent, yes, it becomes a lot easier to see.

Senator GORE. Well, ten miles up above this hearing room the ozone layer right now is 5 to 7 percent thinner than it was 17 years ago, 15–20 years ago?

Dr. WATSON. Of the order of 5 percent, correct.

Senator GORE. Now, 15 years ago what were the scientists predicting would take place as of now above Washington, D.C.?

Dr. WATSON. Of the order in wintertime for this time of year? Of the order of 1 to 2 percent.

Senator GORE. So, instead of 1 to 2 percent, it is 5 to 7 percent?

Dr. WATSON. Correct.

Senator GORE. Now, where does this 2 to 3 percent figure come from? Is that the global average for ozone loss?

Dr. WATSON. Okay, yes. One of the numbers we often report is what we would predict for ozone depletion globally. Part of the so-called global average which is really a fairly meaningless term. And what we are much more concerned about is what the ozone change is as a function of both season and latitude.

So, when I said earlier that under the Montreal Protocol we would have predicted over the next few decades that the ozone would have changed somewhere between 1 and 5 percent, that is the range, what the models would predict taking into account variations with latitude and variations with season.

Senator GORE. Now, if we completely halted all production of chlorofluorocarbons today, what would be the results for the concentrations of these chemicals in the upper atmosphere?

Dr. WATSON. If you were to phase out all chlorine-containing compounds and you were not to allow any substitutes that contained chlorine, the amount of chlorine would increase in the atmosphere for a few more years of the order, I would guess of three to seven years, five to ten years, and then it would start to slowly decrease. But the rate of decrease would be extremely slow.

Senator GORE. How long would it take to get back down to the level that existed 15 years ago?

Dr. WATSON. Probably the order of 100 years or more.

Senator GORE. 100 years or more even if we completely phased out production? But the levels would begin to decline within three to five years?

Dr. SOLOMON. I do not think you would see a perceptible decrease in total chlorine, certainly not as early as three to five years from now. It would probably be at least a decade.

Senator GORE. So, let me get it clear. If we completely halted all production of CFCs tomorrow, then it would still take ten years to see a reduction in the concentrations way up in the atmosphere?

Alternatively, if the only thing we do is abide by this treaty we have signed, we will see within ten years a doubling of the concentrations? Correct me on that.

Dr. SOLOMON. Excuse me, Senator. We will see a doubling in approximately 50 years.

Senator GORE. What about in ten years? What kind of increase?

Dr. WATSON. I am going to guess wildly. If it doubles in 50 years, therefore, I would say another 20 percent would go from 3 to 3½ to 4 parts per billion in the next, say, 10 or 15 years.

Senator GORE. Now, if it increased—and I recognize that is a rough estimate—if it increased 20 percent by the turn of the century in the concentrations, then the amount of damage done to the ozone layer in the polar regions would be an increase of 40 percent, correct?

Dr. TUCK. That is correct, prima facie. But, on the other hand, if you have an ozone hole like we did in 1987, there is not that much ozone left to destroy, so you do start to saturate the thing. But, I mean, that is the worst news it could be.

Senator GORE. That is good news and bad news. The good news would be the rate of destruction might slow. The bad news would be it is because it would be all gone.

Dr. TUCK. Basically what you said is that if you have a 20 percent increase, you are saying it would be something like a 40 percent increase, all other things being equal, and, yes, that is basically correct.

It is my understanding. I do not know if the others agree.

Senator GORE. And nobody disagrees that the single largest cause of ozone depletion is the chlorofluorocarbon family of chemicals, correct?

Dr. WATSON. Correct.

Senator GORE. Now, there are, however, other chemicals which also contribute to the destruction of ozone, halons, which are in fire extinguishers and contain bromine also destroy ozone, correct?

Dr. WATSON. Yes. The bromine has significant potential to destroy ozone. On a per molecule basis it is actually much more effective than chlorine.

Senator GORE. Now, if you compared the damage being done by CFCs to the damage being done by bromines, would it be about 10 to 1 CFCs to bromines?

Dr. SOLOMON. Well, if you look at, for example, the Antarctic ozone hole, it looks like the bromine contributed perhaps 10 to 20 percent of the depletion that was observed in 1987.

Senator GORE. Say that again, please.

Dr. SOLOMON. In 1987 bromine dominated reactions contributed about 20 percent of the total chemical loss while the chlorine was making up the rest of it.

Senator GORE. So, it would be five to one?

Dr. SOLOMON. Something like that.

Senator GORE. What about the carbon tetrachloride that you mentioned as a contributor to the problem? What percent does it contribute to this problem?

Dr. WATSON. I have not got a hard number, but obviously carbon tetrachloride is a long-lived gas, a 50–70 year lifetime. It contains four chlorine atoms. So, on a per pound basis, it is a very efficient gas through which you can destroy ozone.

Much of it is produced and used as a feedstock for producing other fluorocarbons. Most of it is not liberated to the atmosphere, but we have certain hard evidence that it is increasing in the atmosphere at approximately 1 percent per year and we do not understand where that 1 percent per year is coming from.

So, clearly, if one went ahead and had strong regulations on fluorocarbons 11 and 12 and 113, but we did absolutely nothing about the increase in carbon tetrachloride, that indeed will not give you the required protection for ozone.

But the first question is where is the carbon tetrachloride that is being released into the atmosphere coming from? At this moment in time I certainly do not know, and I am not sure that anyone in the scientific community has a good understanding of it.

Senator GORE. All right. So, CFCs, halons and carbon tetrachloride in that order, but by far and away the vast majority of the damage is being done by CFCs.

Now, the more rapid rate of destruction in the polar regions is, as you said, Dr. Tuck, a minor contributing factor to what has happened at mid latitudes—do you agree with that?

Dr. TUCK. Oh, yes. Even if it is a leaky bucket.

Senator GORE. And that is because you had the accelerated destruction at the poles, the air from the rest of the world's stratosphere rushes in, and it dilutes by that amount. But you only have roughly 2 or 3 percent of the earth's surface or of the stratosphere at the poles, and so the dilution would not be that great. Is that the reason why it is a minor factor?

Dr. TUCK. Well, that is the dilution argument, and that is certainly true.

But, on the other hand, what we are not certain about is if the thing is not just a fixed slug of air, but if there is some flow through the system so that air that is getting processed and thrown out to mid latitudes to some extent is lower in ozone than it otherwise would have been if there had been no chlorine in the vortex.

But that also is likely to be a small effect. But, as Dr. Watson said, a few percent at mid latitudes is not without its significance.

Senator GORE. I am puzzled then. If you predicted from the first models of a zone destruction that there would be a loss of 1 to 2 percent and instead it is 5 to 7 percent, there's a discrepancy. You have discovered why the ozone hole over Antarctica took place. You have discovered similar phenomena in the Arctic. What is the explanation for the far more rapid rate of increase of stratospheric ozone at the mid latitudes?

Dr. SOLOMON. I think there are two possibilities. One is the one that has already been mentioned, namely, dilution of the depleted air in the Arctic spreading out to the lower latitudes. The other is the possibility of the same kind of surface reactions that take place on polar stratospheric clouds can take place on background aerosols that exist at all latitudes.

In other words, there is always particulate matter present. It is not nearly as extensive as what you have in the polar stratospheric cloud, but it is there and it could be playing a very important role.

Senator GORE. And so you think there is a possibility that we could discover yet another reason for concern, a brand new factor that could speed up destruction of the ozone in the mid latitudes?

Dr. SOLOMON. Laboratory studies have recently been carried out not only to study the rates at which these reactions occur on ice surfaces, but also to study how fast they occur on the kind of surfaces that exist at lower latitudes, at warmer temperatures.

And they show that the same kinds of chemical processes do occur. They occur more slowly, but they could very well account for some fraction of the enhanced loss of ozone at mid latitudes that you are talking about, Mr. Senator.

Senator GORE. Thank you.

I am pleased to recognize our ranking Republican member, Senator Pressler.

Senator PRESSLER. Thank you very much, Mr. Chairman. I apologize for my absence. We have the Banking Committee in session this morning.

Let me first of all commend the witnesses for their observations.

Let me ask this: How useful will the Earth Observation System be in the area when it becomes operational? And I understand there is going to be a NASA launch in the early 1990s. How important is the Total Ozone Monitoring System Satellite?

Dr. WATSON. The two things you talk about are obviously different. I believe that the total ozone mapping spectrometer is a very important, very simple instrument, but it is a very important instrument. It will help to let us monitor ozone at all latitudes continuously throughout the year with the exception in the deep polar night.

Therefore, I think it is very important to have a base line of how ozone is changing as a function of season and latitude. This is a fairly small instrument which could be deployed on a relatively small rocket.

The Earth Observing System is exactly the opposite type. It is a very large, complex payload to be put into polar orbit on several platforms. In my opinion, it is the type of system that is absolutely required if we are going to make the progress that we need to make to understand the earth as a system.

It will look at not only the atmosphere but at the land and the oceans. It will look at ocean circulation, ocean chemistry, the dynamics of the ecosystems, atmospheric chemistry and atmospheric dynamics and, most importantly, the connections between the atmosphere, the land, and the ocean.

In my opinion, it is this holistic approach to earth sciences, not just a monitoring system but coupled strongly into a strong theoretical basis, that is the way we have to go in the future.

Senator PRESSLER. Anybody else want to comment on any of those points?

Dr. TUCK. I just endorse what Dr. Watson said. I think he is absolutely right.

Senator PRESSLER. Now, as I understand it, the United Nations has been a very important part of the effort to combat ozone depletion. Is this really an effective forum? Do you favor unilateral action by the United States to reduce the use of CFCs and other harmful chemicals, or should we wait for other countries to act? Should we stick with the Montreal Protocol?

If we go forward further ourselves, is that a futile gesture?

Dr. WATSON. That is clearly a policy decision you have to make. I am personally optimistic that there will be actually international action at a concerted level. Therefore, it is clear to solve the problem you need total global support for such an action.

Obviously unilateral action is a step in the right direction, but I believe that it would be much more useful to bring along colleagues, partners, other nations across the world to come up with a common policy.

And the United Nations Environment Program has indeed served as a very, very useful catalytic mechanism to get governments together to discuss issues such as ozone depletion and global warming.

Whether it is the best forum one could possibly debate that. I have personally been impressed by the efforts of Dr. Tolba in both climate warming and in ozone depletion. Given the relatively small budget of the United Nations Environment Program, I believe they are doing a very solid job. They have the confidence of the countries in the East, the West, the North, and the South.

Senator PRESSLER. Which country is the worst abuser, so to speak, or produces the most? I am told the East Germans do very little to control this. I do not know.

Are there some countries that are worse abusers than others? Please give me a rating of the worst countries in terms——

Dr. WATSON. You are not going to like the answer—the United States. On a per capita basis, the United States uses as much or more fluorocarbons than other country in the world. We are very comparable now to most European countries. That is about one kilogram of fluorocarbons per capita per year.

We have, of course, got some regulations and we have obviously been pro-active on this particular issue, but we still per capita use more than any other nation in the world the same as we use more carbon dioxide per capita than any other nation in the world.

Senator PRESSLER. Which countries are second and third?

Dr. WATSON. The Soviets are catching up fast, unfortunately, but I do not know the hard numbers on carbon dioxide. We are clearly for 5 percent of the world's population we use roughly 25 percent of the total fossil fuel in the world. I do not know who is second.

The Europeans typically are half of us both in carbon dioxide emissions, but I am not sure where Soviets fit. They are coming up fast.

Senator PRESSLER. When the average person hears that there is an increase in ozone in the lower atmosphere, he normally asks why this ozone will not make up for the ozone loss in the upper atmosphere. Can you explain for the record why this is not true?

Dr. WATSON. It does partially make up in one way, but not in a beneficial way, in my opinion. It does not matter where the ozone is above the earth's surface when you are worried about protecting the air from harmful ultraviolet radiation. It does not matter really whether it is at 50 kilometers or five kilometers.

So, unfortunately, the production of methane, the increase of methane in the atmosphere is leading to an increase of tropospheric ozone. However, that is not a good thing.

The ozone, as I said earlier on the record, is an infrared gas that can lead to global warming. It is also a pollutant such that ecosystems and human health are adversely affected by tropospheric ozone. So, while there is some offsetting effect from the increase of tropospheric ozone and the destruction of stratospheric ozone, that

is a policy of one pollutant, methane, offsetting the impact of another pollutant, CFCs.

So, with respect to ultraviolet radiation, there is an offsetting compensation. But with respect to other issues such as global warming, we are moving in the wrong direction.

Senator PRESSLER. Now, you may have covered this, but is the federal budget equipped to carry out the mission of the additional things we must do to determine the rate of ozone depletion in the Arctic? And if not, what should it be?

Dr. WATSON. I think overall the federal budget is reasonably adequate to look at these issues.

As you know, I am in a difficult position to answer this question. However, I do see some hope that where I believe we made an aggressive start is in moving forward with looking at global change things like EOS, the global change programs of NOAA, the similar geosciences programs in the National Science Foundation and other things that are likely to be put on the table by the other agencies within the next couple of years from DOE through to EPA are absolutely vital if we want to understand our global planet.

Scientists can always spend more money, as you obviously well know. I would say that in the area of stratospheric ozone, one could clearly see new additional systems are needed, such as a ground-based network to be able to monitor the long-term change of ozone. But even more what is needed is a holistic approach to understand how the atmosphere, ocean and land interact.

Senator PRESSLER. Then I guess that holistic approach leads me back to my earlier question on the Earth Observation system. If that did not come into play—I know you have commented on that—would that make a big difference in terms of finding a solution?

Dr. WATSON. In my opinion, yes. I believe missions such as the Earth Observing System and the parallel efforts of the other agencies in Washington are absolutely essential if we want to understand how our earth works, and I believe that is essential in the cost benefit approach.

If we are going to think about regulating industries, the better our scientific knowledge, the wiser our regulatory policies can be. So, I believe that programs like the global change program being initiated by the National Academy of Sciences, the International Geosphere Biosphere Program being coordinated by the International Council of Scientific Unions—these are absolutely essential.

There must be international programs with very strong support by the United States and in very close coordination between the different science agencies such as NASA, NOAA, NSF, DOE and the others.

Senator PRESSLER. Mr. Chairman, thank you very much.

Senator GORE. Thank you very much. I have a few other questions before we wrap up the panel.

You said, Dr. Solomon, that there could be a kind of a positive feedback loop for the formation of polar stratospheric clouds because the depletion of the ozone layer in the stratosphere would, at that altitude, produce further cooling and likely enhance the creation of polar stratospheric clouds which in turn would be expected to increase the rate of ozone destruction.

Dr. SOLOMON. That is correct.

Senator GORE. So, you get a vicious cycle going.

Now, the CFCs which cause that effect are also greenhouse gases and contribute as much as 20 percent to the global warming problem.

Help me understand how they could produce a cooling in the stratosphere and a warming below the stratosphere.

Dr. SOLOMON. Well, the fact that the stratosphere cools as greenhouse gases are introduced is a complicated process—there are several aspects to it. The one that I mentioned was just the fact that ozone itself is the major source of heat for the stratosphere. So, if you remove ozone, you will cool the stratosphere.

The fact that you are also increasing the abundances of the chlorofluorocarbons and especially carbon dioxide actually and paradoxically makes the situation even worse because although carbon dioxide warms the lower atmosphere, greenhouse warming, it actually cools the stratosphere and it should produce significant cooling in the lower stratosphere, especially in polar regions.

Senator GORE. Why?

Dr. SOLOMON. Primarily because it is looking—well——

Senator GORE. It keeps the infrared from getting back up to it?

Dr. SOLOMON. It is trapping outgoing infrared radiation in. In the troposphere temperatures decrease as a function of altitude. If you ever go mountain climbing, you know that it gets colder as you go up. So, you are looking at temperatures that are warmer beneath you than the altitude where you are.

The definition of the stratosphere is that it is the part of the atmosphere where temperatures increase as a function of altitude. Therefore, the outgoing infrared is actually characteristic of a colder temperature than the local one which means that if you trap it, it is going to get colder rather than warmer.

Senator GORE. I have seen these graphs of temperature as a function of altitude where it will get colder as you go higher. But then, when you get to the stratosphere where the ozone layer is, it suddenly gets warmer again until you get to the top of the stratosphere, and then it gets very cold.

Dr. SOLOMON. That is correct.

Senator GORE. But it is the ozone itself which causes that warm layer of air eight to ten miles up, correct?

So, what you get then is a change in the balance and as the atmosphere below that level warms up—the stratosphere where the ozone layer is actually gets colder.

Now, would the combination of the lower warming and the upper cooling also tend to produce more polar stratospheric clouds?

Dr. SOLOMON. I would certainly think so.

Senator GORE. And so you could get this vicious cycle that actually speeded up the destruction of the stratospheric ozone layer?

Dr. SOLOMON. Yes. And I think a good example of how important that can be are the observations from Antarctica. Even though chlorine was slowly increasing in the atmosphere, it did not get an ozone hole that slowly increased. It happened very rapidly over a time period of only a few years.

There has to be a positive feedback mechanism involved in there.

Senator GORE. Do you think that is what it is?

Dr. SOLOMON. I think that is probably very important.

Senator GORE. Is there a chance of a similar sudden appearance of an ozone hole in the Arctic?

Dr. WATSON. I do not think you can rule it out because we believe the efficiency of the chlorine is more dependent quadratically on the concentration of chlorine.

Senator GORE. Wait a minute. That is the first time we have heard quadratically at this hearing. We have heard a lot of scientific lingo.

Dr. WATSON. You double the concentration. It goes up by a factor of four because there is a nonlinear relationship then. I think there is the potential for a rapid onset of decrease of ozone in the Arctic. Whether it will occur is very hard to predict, but there is certainly the potential for that.

I do not think there is any doubt.

Senator GORE. I am going to come back and ask that question again and try to get you to answer it a little more simply. But let me lay down a predicate first.

Why does the rate of damage at the poles increase twice as fast as the volume of the chemicals doing the damage?

Dr. WATSON. Very simply the chemical reaction that leads to the destruction of ozone is a chlorine monoxide radical reacting with itself to form a dimer.

Then photolysis occurs with sunlight to go back to chlorine atoms and the two chlorine atoms you liberate from the dimer both react with an ozone molecule to go to ClO again. So, it is dependent on the—ClO has to react with itself and therefore just because two of them are reacting together, it is dependent, as I said, quadratically on the square power of the concentration. You need two of them to make it work.

Senator GORE. And just because you need two of them to make it work, why does that double?

Dr. TUCK. Because the speed of the convoy is the speed of the slowest ship, and there is a sequence of chain reactions and the particular reaction that Bob alluded to, the chlorine monoxide reacting with itself, is the one that is the slowest.

So, the rate at which the whole process goes is determined by the rate of that step.

Senator GORE. Okay. So, when you double the number of those chlorine radicals, then you get a fourfold increase in the resulting chemical reactions that actually destroy the ozone layer.

So, when you get a doubling over the next five decades, you do get a fourfold increase in the rate of damage.

Dr. WATSON. And if there are triple the chlorine, you would have nine times the damage, just to put it in perspective. It is always the concentration of chlorine times itself. So, two times two would be four, three times three would be nine.

So, in other words, it is a very nonlinear system.

Senator GORE. Now, what you mean by nonlinear is that when it changes step by step by step, it can suddenly reach a point where the way the atmospheric system in the Arctic operates, it does not just change by degrees, but suddenly changes in a fundamental way. And that is what took place in Antarctica.

And you are saying there is the potential for exactly the same sudden opening of an ozone hole to take place in the Arctic?

Dr. SOLOMON. I think that all the observations that we have from this last mission show that the Arctic stratosphere looks a heck of a lot like the Antarctic stratosphere in terms of the concentrations of dangerous substances like chlorine monoxide. Whether or not it is close to the edge is really the question. How close to the edge is it, and that is not one that we can answer simply. But clearly it is a matter that we need to be concerned about.

Senator GORE. Now, I want to understand what factors are involved in your analysis of how close we are to that edge. One is the tightness of the vortex in the Arctic, correct?

And you are saying that from year to year that vortex can in some years get tighter and persist a longer period of time after the sun comes up, correct?

Dr. TUCK. It varies from one year to the other, particularly in the Arctic.

Senator GORE. That is one variable, correct? Another variable is the increasing volume of the chlorine radicals.

Dr. SOLOMON. Yes.

Senator GORE. Is there reason to believe that if you had the same atmospheric conditions and a weak vortex, a wandering vortex, same temperatures, etcetera, that merely a much larger increase in the volume of chlorine radicals could, by itself, cause the onset of a nonlinear change. Do we know that or not?

Dr. TUCK. I do not think we really know it. But let us keep the phrase weak vortex in the Arctic in perspective. It is not that weak.

All the evidence was, you know, using the same meteorological quantities to describe the vortex and its tightness that we used in Antarctica.

There is no question the Arctic vortex is a well defined entity and, to the best of my knowledge as of a couple of days ago, it was still hanging in there, and we left it on February the 10th knowing that there were 800 parts per trillion of ClO in it.

And despite the fact that the Arctic vortex is warmer than the Antarctic, another way of looking at the question is to say, is there some level of chlorine where all other things being held equal, is there some level of chlorine where we are going to trigger some detectable ozone loss, just as we did in Antarctica.

We have got no reason to answer that question with anything other than yes. But we do not know quantitatively how it is going to happen. I think that is the point.

Senator GORE. Now, in Antarctica when the sun comes up the reaction begins to take place and continues for what, two and a half months?

Dr. WATSON. Yes, and that is the biggest difference between Antarctica and the Arctic. The vortex clearly on average hold together for a couple of months after the sun comes up and so you have these high concentrations of ClO radicals, and you have of the order of 50, 60, 70 days for the chlorine to then destroy the ozone.

So, you need high ClO and you need sunlight.

Senator GORE. Now, in the Arctic the vortex begins to dissipate after the sun comes up quickly?

Dr. WATSON. Often even before the sun significantly comes up.

Senator GORE. Why?

Dr. TUCK. It is to do with a phenomenon called the sudden stratospheric warming. The stratosphere and the vortex respond to the evolution of highs and lows, cyclones and anticyclones in the troposphere, and there is a lot we do not understand about the dynamics of those things, but in some winters, roughly half the winters in the Arctic, you have an event where one of these things happens. The vortex splits into two, and the temperatures rise rapidly.

Now, that does two things. If you split the vortex into two, you almost certainly increase the rate of fluid mechanical mixing of that would dilute any PSC process there, so it would cut off the chemistry.

The other thing is when you do that, you raise the temperatures, so you stop any more production of PSCs unless—sometimes those events happen so early in the winter that the system has time to recover and reestablish a cold vortex somewhere around the middle or end of February. So, it is very, very variable.

There have been some winters in the Arctic where the vortex, the westerly winds have hung together at the altitudes we are talking about until April or May, but that is not a common occurrence.

Senator GORE. So, the simple way to put it that the wind patterns and the high pressure and low pressure patterns in the Arctic are different than they are in the Antarctic and so this vortex usually begins to break up sometime in January or February before the sun comes up.

Dr. SOLOMON. Sometime around February or March normally.

Senator GORE. Sometime around February or March.

Now, can the ozone destruction take place in the absence of sunlight?

Dr. SOLOMON. No.

Dr. TUCK. Not to the best of our knowledge, no.

Senator GORE. So, the fact that the vortex usually disappears before the sun comes up is probably what has thus far prevented the creation of an ozone hole over the Arctic, correct?

Dr. TUCK. I would not like to state it quite that simply, but I think that is a very important mechanism in what is going on. But there is something else that comes in. If you look at the way the vortex acted this year——

Senator GORE. I prefer Dr. Watson and Dr. Solomon nodding affirmatively, but you go ahead, Dr. Tuck.

Dr. TUCK. I am afraid I am not one of Harry Truman's one-armed sign painters.

Senator GORE. We have noticed that, but we appreciate it, too. Go ahead.

Dr. TUCK. Towards the end of our mission, the vortex moved down over the Baffin Sea in the northern part of Canada and it is displaced significantly off the pole. That means where the air is going round and round in that vortex on the southernmost parts of that vortex. It is getting exposed to quite a lot of sunlight. So, that is what we mean when we say that. It is the reason I did not like the statement when the sun comes up.

It is beyond any doubt true in Antarctica that you do need the increasing amount of sunlight that becomes available as equinox—

spring—approaches. But, on the other hand, if the vortex moves off the pole or gets distorted, and it does in both hemispheres, there will be air that is making excursions out to low latitudes where it gets some sunlight, and that still happens. While the vortex is distorting it, it does not break up.

Now, to get the full-blown 1987 Antarctic effect, you do need the thing to hang together as an entity until the sunlight is back to the whole of the vortex. But, nevertheless, you cannot rule out the possibility—indeed I think it is even likely—that you are going to get loss of the edge of the vortex before spring equinox simply by virtue of the mechanism I have said, that you get bulges of the vortex out to lower latitudes where it gets some sunlight and you are going to get some ozone loss.

Senator GORE. Okay. So, in the Antarctic vortex it hangs over the South Pole and while in the Arctic it can wander. The Arctic vortex can separate into two vortexes. It can come down further south where it will get the sunlight earlier in the year and the edges of the hole, the edges of the vortex could see rapid ozone loss, correct?

Dr. TUCK. Correct. The balance of the things is different but basically what you are saying is correct.

Senator GORE. All right. Dr. Solomon, I read an article by someone who said that your science developed in the Antarctic was clearly questionable because of the weaker ozone hole this year. I do not agree, as you might expect, but you may know the article I am talking about.

He said that there was this unpredicted lessening of ozone loss this past year, and so this called into question the basic science. Actually, it was not unpredicted, was it?

Dr. SOLOMON. I would say it was not unpredicted. As I am sure you know, the process of debate is an essential element in arriving at scientific truth. And probably the fact that the scientific community is as united as it is regarding especially Antarctic ozone depletion is a strong signal that this problem has been clearly understood by most people.

The fact that 1988 exhibited less ozone loss than 1987 was not wholly unexpected. One would have expected it based on observed records of temperature which indicate that, on average, every other year is colder than the one before.

And so, since 1987 was an exceptionally cold year, 1988 should have been expected to be a relatively warm year. We do not really understand the mechanisms that are responsible for that statistical correlation, but nevertheless it exists and it has held up pretty well over the last eight or so years.

To make things even more complicated, it is not exactly a two-year period, so I should mention that.

Senator GORE. About 27 months.

Dr. SOLOMON. So, 1989 in Antarctica will also be a relatively warm year which will bring more and more of the type of statements that you are talking about to bear.

But, nevertheless, if one looks carefully at the temperature record, one can understand why the Antarctic ozone depletion was less pronounced in 1988 than 1987.

Senator GORE. Now, just a couple questions on the effect of the increased UV radiation within the ozone hole on the sea vegetation, what do we know about that?

Dr. WATSON. I think unfortunately very little. All studies that have been done tend to show that more ultraviolet radiation has adverse effects on phytoplankton, but to quantify it I believe is beyond the state of science at the moment.

Senator GORE. Well, there was a study reported recently indicating that phytoplankton decreased their photosynthetic activity down to a level less than one eighth of what is normal in the presence of increased ultraviolet radiation that was comparable to what they get when the ozone hole appears in Antarctica. Are you familiar with that study?

Dr. WATSON. To be honest, no.

Senator GORE. Well, we are going to have a follow-up hearing or hearings on some of these more detailed questions. Should we not be doing that research on an accelerated basis?

Dr. WATSON. In my opinion, yes.

Senator GORE. I mean, the food chain of the entire ocean largely depends upon phytoplankton, correct?

Dr. SOLOMON. The food chain of the southern oceans is critically dependent on phytoplankton. It is the base for everything that exists in the southern ocean including whales, seals, penguins, fish that people eat, et cetera.

Senator GORE. Not only that, but phytoplankton represents or plankton generally represents one of the pathways by which the southern ocean absorbs CO_2 from the atmosphere, correct?

Dr. WATSON. Yes, it plays a very important role.

Senator GORE. And phytoplankton specifically played a key role in the formation of moisture-bearing clouds with the emissions of DMS, correct?

Dr. WATSON. There is at least a speculation by Bob Charlson and that is a very important process and may be important in the whole global warming issue. I think it is a very key area of research is to understand the emissions of dimethylsulfide from the oceans and then how they go into the atmosphere to form the nucleus for clouds. I think it is a very key area. It is an active area of research.

Senator GORE. All right. Now, just finally on money, the intensive short-term research efforts like the Arctic expedition and the Antarctic ozone expeditions have been funded largely from existing agency budgets, correct?

Dr. WATSON. In NASA certainly completely out of existing budgets, and I believe that is true for NOAA. There were no new augmentations for other NASA or NOAA to do either the Antarctic or the Arctic expeditions.

Senator GORE. Have other important programs suffered so that these urgent emergency expeditions could go forward?

Dr. WATSON. Clearly priorities had to be made whereby other types of research that was clearly important had to be put on the back burner.

In my opinion, these two expeditions were so important for science and society, they had to be given the highest priority. Obviously when they cost $5 to $10 million each other parts of research

that one would like to see actively pursued had to be put on a slower pace.

Senator GORE. Now, the Chemical Manufacturers of America provided some research funding for both the Arctic and Antarctic expeditions, correct?

Dr. TUCK. Yes.

Senator GORE. Now, some of the proposed replacements for CFCs contain hydrofluorocarbons. Am I correct in saying that they do not deplete the ozone layer but they are greenhouse gases, though somewhat weaker in their greenhouse effect than the CFCs?

Dr. WATSON. It depends what the chemical composition of these substitutes is. If they contain a hydrogen atom and also contain a chlorine atom, which some of them do, then they will weakly destroy ozone and weakly cause a greenhouse effect.

So, in other words, they do have the potential for some level of ozone depletion and some level of global warming, albeit much lower than fluorocarbons 11 and 12. It depends on the exact chemical.

If it contains no chlorine at all, then it would have no ozone depleting potential but would still have some small greenhouse forming potential.

But if it includes any chlorine at all, it would have some level of potential to destroy ozone.

Senator GORE. All right. Well, I appreciate all of you helping us out today, and I am sorry we kept you so long, but this is a complicated area, and it is vitally important that we understand the science.

I think what you are telling us that we have the potential for a major global catastrophe.

And, in fact, we are seeing a slow motion catastrophe unfold right before our eyes right now, and it is not to slow motion.

As we saw in Antarctica, it can occur with dizzying speed, and that could be repeated over the Arctic.

In any event, thank you very much. We will go to our second panel now. Thanks to the three of you.

[The following information was subsequently received for the record:]

WRITTEN ANSWERS TO QUESTIONS SUBMITTED TO DR. ADRIAN TUCK FOR THE RECORD BY THE SENATE COMMERCE COMMITTEE

From Senator Hollings

1. I recognize that you are probably still recovering from the long deployment and rigorous hours of work required during the Arctic expedition. Still, I'd like you to turn your attention to the future.

   What's next? Which key questions about ozone depletion still need to be answered?

Answer

The next key question in my view is to what extent the polar vortices of the lower stratosphere during late winter and early spring export ozone loss to the lower latitude belts which surround them. There are at least three mechanisims by which such loss may occur: (i) formation of the type I PSCs outside the edge of the polar vortex, with some subsequent ozone loss there, (ii) export of chemically perturbed air from inside to outside the vortex, (iii) loss by dilution following the final breakdown of the vortex. Of these, I regard (ii) as potentially the most important.

Are any more research expeditions planned?

Answer

Currently, there are no more expeditions planned, but they are clearly needed beyond 1991.

2. EPA has estimated that ozone depletion will lead to increased UV radiation and millions of additional cases of skin cancer.

   Please outline the other expected impacts of ozone depletion.

Answer

Loss of stratospheric ozone may affect tropospheric climate, but the magnitudes and even signs of the effects are very uncertain. Loss of ozone is likely to cause cooling in the stratosphere.

Increased UV flux at the surface has the potential to cause biological and ecological damage, as well as increased incidence of skin cancer in humans.

Which of the reported impacts worry you the most?

Answer

If (and my impression is that this is a very uncertain area) increased UV fluxes can alter the natural abundances of plankton near the ocean surface, this would be a major cause for concern.

3. Do we understand enough about the proposed CFC replacements to know that they won't harm the ozone layer?

Answer

Calculation of the ozone destroying potential (ODP) of any given CFC or CFC replacement is done by a one or two dimensional photochemical model. A critical quantity is the lifetime of any such molecule in the model stratosphere; such lifetimes are somewhat in question, because of the apparent failure of models to reproduce the low values of tracers such as N_2O, CF_2Cl_2 and $CFCl_3$ observed at 16-20 km in the polar vortices. The likely sign of such an effect would be for the models to overestimate the ODP of a CFC or CFC replacement. In my view, model-based stratospheric lifetimes must be considered uncertain by a factor of two or possibly more.

4. Several of the proposed replacements for CFCs contain hydrofluorocarbons (HFCs) or hydrochlorofluorocarbons (HCFs). HFCs do not deplete the ozone layer, but they are greenhouse gases.

Will they contribute to greenhouse warming as much as CFCs do?

Answer

I don't know the answer to this question.

5. Although we usually try to separate the problems of ozone depletion and global climate change, the two are interrelated. Changes in the chemistry of the stratosphere will lead to changes in temperature as well. Global warming will change ozone depletion rates since the rates of chemical reactions depend on temperature.

Do we know how climate change may affect ozone depletion?

Answer

We know how some individual processes of climate change would affect ozone depletion, but the overall process has sufficient complexity to be beyond our predictive capability at present. It is plausible that CO_2 increase can lead to cooler stratospheric temperatures. In the upper stratosphere, this leads to more ozone production (i.e. less loss from CFCs). In the polar vortices, it could lead to more PSCs in late winter and spring, and hence more ozone loss. However, there is evidence from the recent aircraft missions that major PSC events are faced by synoptic scale weather systems, and it is not known how this mechanism will be affected by climate change. A fair summary would be that we don't know the sign of the effect, let alone the magnitude.

There may be agreement among some scientists that we know how ozone depletion will affect stratospheric temperatures and global climate patterns. In my view, however, we cannot yet predict this with confidence.

From Senator Kasten

6. I understand that with respect to the CFCs, which are the general classification of the substances which cause ozone depletion, that there are some which are much more damaging than others. Also, I understand that there are other substances, which are not CFCs, which have been found to contribute to the problem. As we look toward developing policies on the use of ozone depleting substances, could you comment on whether there are some CFCs which are more damaging than others and whether there are other substances beyond the CFCs on which we should begin to focus?

Answer

This is a complicated subject. From the point of view of ozone depletion, it is qualitatively true that chlorofluorocarbons which contain a double bond or an H atom will do less damage to stratospheric ozone than those which don't, on a molecule for molecule basis. However, many other factors, such as toxicity, safety, affordability and convenience enter into this question. I am not competent to comment on such factors.

Senator GORE. We are now going to hear from a panel of manufacturers and users of chlorofluorocarbons, Dr. Joseph Glas, director for Freon products at the DuPont Company; Dr. Robert Traflet, President for fluorine products at Allied-Signal, Incorporated, Dr. Arnold Braswell, President of the Air Conditioning and Refrigeration Institute in Arlington, Virginia. If you could all come forward.

I would like to welcome all three of you. In this first hearing on the science of the chlorofluorocarbons and ozone destruction and the greenhouse effect, I wanted to have representatives to present the industrial perspective unchallenged by witnesses from public interest groups, or the EPA, to give you a chance to present your best case and to respond to questions.

In coming weeks, we intend to hold other hearings, including a second hearing on this subject, featuring witnesses who will discuss the impacts of stratospheric ozone depletion on human health, agricultural crops, aquatic organisms, the food chain and the like.

But I want to welcome all three of you and without objection, your prepared statements will be included in the record in full.

Dr. Glas, I will begin with you, if you like. Feel free to highlight your statement or to present all of it, as you see fit.

STATEMENT OF DR. JOSEPH GLAS, DIRECTOR, FREON PRODUCTS, E.I. DUPONT, INC., WILMINGTON, DE

Dr. GLAS. Thank you, Senator Gore.

Members of this subcommittee, my name is Joseph Glas, and I am the Director of Freon Products Division of the DuPont Company. I am appearing before your Subcommittee to provide to you our views concerning questions raised in your letter of February 8.

We have reviewed the information released last Friday, by the Airborne Arctic Stratospheric Expedition, and we have no reason to take issue with the summary of their findings.

Although the expedition has not found depletion of magnitude that has been observed in the Antarctica, they did find a perturbed stratosphere as the previous panel has testified.

We believe that the conclusions published by the NASA Ozone Trends Panel, last March, continue to be valid. The new information today reinforces our decision, as a company, to phase out of CFC production as soon as possible and no later than the turn of the century. These findings also support the wisdom of the Montreal Protocol, which not only established a phase down schedule, but provided a mechanism to adjust the speed and the stringency of the phase down if new scientific evidence supports such measures.

We continue to believe that a total phase out of CFC production is needed to assure protection of stratospheric ozone, and we are working as hard and as fast as we can to develop alternates to these products so that the transition away from CFC's will not result in a disruption to our society or widespread use of substitute materials that could cause other environmental or health problems.

Senator GORE. Dr. Glas, could I interrupt you just briefly at that point?

You compliment the treaty for having the mechanism which allows adjustment as new scientific evidence arrives. Do you be-

lieve that the findings that we have just heard warrant tightening the schedule for phasing out CFC's?

Dr. GLAS. Certainly warrant the stringency and as far as the schedule is concerned, probably the schedule as well.

Senator GORE. So you think these scientific findings justify phasing out CFC's more quickly than the Montreal Protocol currently calls for?

Dr. GLAS. Well, the Montreal Protocol does not call for a phase out; they call for a phase down. And the key is, as the previous panel has testified as well, the key is to a total phase out. And to deal with that, as I will testify later, there are some important societal considerations of how we manage this in an orderly way and get total global support.

Senator GORE. But at this point, you believe that the new scientific evidence justifies toughening the Montreal Protocol?

Dr. GLAS. Indeed.

Senator GORE. Excuse me, go ahead.

Dr. GLAS. And to the point of a total phase out.

Senator GORE. All right.

Dr. GLAS. We believe that the free enterprise system can successfully meet the challenge of a total CFC phase out, if it is allowed to work. This will be a monumental task, since numerous industries will need to adapt to the new alternatives and possibly new technologies. We have attached a brief listing of the many needs that CFC's fill today and we believe that those will have to be dealt with in an orderly transition.

This will require careful, yet ambitious transition programs. We also believe that the governments of the world need to be supportive of the needed changes and provide clear signals as to stringency and timing of future regulation to the affected industries that will need to restructure to accomplish an orderly transition to alternative products and technologies.

We believe that clear communication and cooperation among industry, government and scientists and environmental groups must be fostered if we are to successfully accomplish the tasks that lie ahead.

We must continue to rely on fluorinated hydrocarbons as the principal alternative to the CFC's. Some of these alternatives will also contain chlorine. The mix of alternatives will have an ozone depletion potential of less than 5 percent that of 11. We believe that will be satisfactory.

Such materials will allow the transition to be accomplished in an environmentally acceptable manner.

To illustrate the basis for this last conclusion, I have attached a graph from an EPA analysis showing the effect of a phase out of CFC's and a phase-in of alternatives on the concentration of stratospheric chlorine. This analysis shows that the impact on the environment of not achieving 100 percent compliance to the phase out of CFC's use.

In both cases, a family of alternative products are assumed to be available as substitutes for the CFC's. The upper case shows significant impact of only obtaining 92 percent versus 100 percent compliance. Hence it is critical to make a global transition to alternatives. This will only be done if affected industries have the opportu-

nity to make a transition to new technologies. We also believe that the alternatives we have identified offer the most rapid and environmentally responsible route to the new technologies.

We have studied the recent claims that certain non-halogenated alternatives could be used for applications such as refrigerants and electronics cleaning. These technologies will find some use, but in our view, they will not be practical substitutes for CFC's in the foreseeable future and they will not find widespread application.

If consumers are blocked from both CFC's and the alternatives we have identified, there will be significant disruption in global economies and life styles.

To summarize, the technical challenge is to develop alternatives with the desirable properties of CFC's but with little or no potential to effect the ozone layer. There is no single alternative that has the complete range of properties offered by the CFC that it would be targeted to replace. All represent a compromise, whether it be in flammability, toxicity, energy efficiency, suitability for existing equipment or performance in use.

In the limited time provided, I would like to comment only on the refrigeration, air conditioning segments. Looking at the chart, on the overhead, if you would please, you will see that approximately 60 percent of the U.S. market for refrigerants is serviced by CFC's 11, 12, and some specialty CFC's, such as 113; 114, and 115. The remaining 40 percent, served by refrigerant 22, possess only 5 percent of the ozone depletion potential of CFC 11.

Refrigerant 12 serves 50 percent of the refrigerant market. It is used in automobile air conditioners, commercial refrigeration and air conditioning, home refrigerators and freezers, and supermarket refrigeration. Only 16 percent of CFC 12 is used in new equipment, the largest segment being automobile air conditioners, which use about 25 million pounds per year.

So, by difference, 84 percent of CFC 12 is used to service the large inventory of existing refrigeration and air conditioning equipment during their useful lives, which range from eight to 40 years. While candidate refrigerants are similar to CFC in some physical properties, the compounds are sufficiently different to require major changes in equipment now in use.

Therefore, we are working with the equipment manufacturers to provide candidate refrigerants and thermal dynamic property data which they need for redesign of their products. We believe the alternative HFC 134-A will find applications in some, but not all of the equipment designs. It has the desirable feature of zero ozone depletion potential.

We are operating two small plants to produce market development quantities and product for toxicity testing. We are also building a commercial scale plant scheduled for start up in late 1990. We believe our commitment will stimulate the design of new equipment to use our product so that further phase down required in 1993 can be accomplished with minimum pain.

There are substantial technical hurdles which producers and users will have to overcome before the commercial products can be introduced, but I am confident that we will be successful.

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The greater challenge for the short term is the service segment which consumes almost 200 million pounds per year; one-half of that in automobile air conditioners.

We have recently announced a new line of developmental blend products which we believe might serve most of this market segment, but even with this product, modest but cost effective equipment modifications will be needed.

The two most promising blends result in reductions of ozone depletion potential versus 11, of 98 percent and 60 percent respectively. Much work remains to be done, however, to prove commercial viability of these products.

The greater challenge is the service requirement for the large industrial chillers which employ refrigerant CFC 12 or 11 and would be used, for example, to cool this building. These are large machines of 200 to 10,000 tons or more cooling capacity. They use 500 to 2,000 pounds of refrigerant 11 or 12, and cost $500,000 to $2 million installed.

There are some 120,000 of these units worldwide, providing air conditioning for large buildings, such as hospitals, office buildings and refrigeration for industry. Retrofit of these units is the only practical approach to accomplish a phase down of CFC use in these machines. Global capacity to replace these machines is only 1,200 units per year, assuming a satisfactory refrigerant were available.

DuPont operates about 350 of these large units in our facilities worldwide. We have initiated a program to develop retrofit technology working in close cooperation with the equipment manufacturers. The best candidate to replace CFC 11 in these chillers is HCFC 123.

We have converted two of our industrial CFC 11 chillers to use HCFC 123 and operating performance is satisfactory. However, we have observed a capacity loss of about 15 percent, which we believe can be corrected by equipment modifications.

We are producing market development quantities of this compound in our plants in Europe and Japan and we are operating a pilot plant to develop basic data for design of commercial facilities.

We are also planning a retrofit test of a CFC 12 unit with replacement refrigerant 134-A later this year. We plan to share our experience when the work is complete and to modify our units as the retrofit technology is developed.

I am concerned about the suggestions of some environmentalists and members of Congress that HCFC 22, which serves 40 percent of the market be banned. It is used in millions of residential cooling systems and heat pumps and has low potential to deplete ozone.

In fact, if all the chlorine in the atmosphere had been carried there by HCFC 22 only, there would be no Antarctic ozone hole. There is no viable substitute for HCFC 22. The threat of regulating HCFC 22 is a major threat for most of the products that we have to offer as replacements. The threat of banning or restricting the use of 22, in the future, will inhibit conversion and prevent the introduction of alternatives I have discussed today.

In summary, while the free enterprise process is making enormous progress, there are many technical hurdles and institutional barriers to overcome as we plan for an orderly transition to a global phase out of CFC's by the turn of the century.

These hurdles and barriers include incomplete basic data and design for world scale plants, lack of complete toxicity profiles, incomplete or inconsistent thermodynamic or transport property information, incomplete development of equipment that can use the alternatives, signals at EPA and in the halls of Congress that some of the identified alternatives may not have normal product life cycles, high capital needs and an uncertain future, threats in the U.S. of auctions or taxes that will divert needed revenue streams from the private sector to the government's general fund, and the need to complete development and design retrofit technologies so current equipment will serve its useful life.

I hope that my testimony will be of assistance in guiding your development of policies to address the issues that face us.

Thank you, Mr. Chairman.

[The statement follows:]

STATEMENT OF JOSEPH P. GLAS, DIRECTOR, FREON® PRODUCTS DIVISION E. I. DU PONT DE NEMOURS AND CO.

Mr. Chairman, members of the Subcommittee, my name is Joseph Glas. I am Director, Freon® Products Division of the Du Pont Company. I am appearing before your Subcommittee to provide our views concerning the questions raised in your letter of February 8, 1989.

You have asked first that we provide a summary of our response to the recent research findings that chlorofluorocarbons (CFCs) are causing depletion of the stratospheric ozone layer. By way of background on our position, I am including in this testimony, a copy of the text of a talk that I gave before the National Academy of Engineering last September that discusses the history of the development of the science that I believe places Du Pont's response to the science in perspective. (See Attachment A.) [1] Based on the findings of NASA's Ozone Trends Panel which was announced on March 15, 1988, the Du Pont Company decided and publicly announced that it had set as its goal an orderly transition to the total phase-out of fully halogenated CFC production as soon as possible, but not later than the turn of the century. As part of this policy, we recognized the basic societal needs that are dependent on these compounds and stated that the introduction of alternative chemicals would be an essential part of the phaseout. We made our decision recognizing that action by a single supplier or single country would be inadequate to protect the ozone layer. We called for acceleration of ratification of the Montreal Protocol and then for prompt initiation of the Protocol's assessment process to consider further global limitations on the emissions of CFCs. The protocol has now been ratified, is in force, and the assessment process has been accelerated.

It is clear from recent findings that chlorine from manmade compounds is, in some fashion, participating in what had been observed Antarctica. The contribution of chlorine from manmade compounds to the observed decreased in ozone in other portions of the globe are less certain. However, even though there continue to be uncertainties in the science, we believe that there is a fundamental agreement that chlorine from manmade compounds plays a role in Antarctic ozone depletion, may play a role in depletion elsewhere, and there is a need for controls beyond those now included in the Montreal Protocol.

This is consistent, insofar as we can tell, with the preliminary findings of the recently completed Airborne Arctic Stratospheric Expedition. We have reviewed the information released last Friday by these scientists and have no reason to take issue with their published findings.

Thus, we believe that our commitment to cease production of CFCs continues to be the correct course of action.

We also continue to believe that an orderly transition to substitutes, rather than a precipitous cessation of manufacture, continues to be a prudent course of action for protection of stratospheric ozone and for protection of the global safety, and health and the well being of the economies of the world.

This leads me to your second question which asks me to discuss the difficulties that Du Pont anticipates in finding suitable alternatives for CFCs. I will, of course,

[1] The attachments referred to were not reproducible and are in the Committee files.

discuss the difficulties but I also will discuss the challenges, opportunities and progress with regard to the development and introduction of alternatives to CFCs.

The task we face is truly monumental and the goal will not be achieved unless we obtain the global cooperation of industry, government, scientists, environmental activists, and consumers. The phaseout of the use of CFCs over a time period possibly as short as a decade is exceedingly ambitious. In developed economies such as ours, every citizen, every day relies for his or her health, safety, comfort and productivity on the substances that we call CFCs. A brief summary of many of the applications of CFCs is included in Attachment B. I will review later the role that CFCs play and solutions that we believe that we have identified.

The underdeveloped economies of the world will require an appropriate share of CFCs during the transition and must, then, have alternatives to support the growth in their economies or we can not hope to have them join in the movement away from the use of CFCs. Thus, the policy choices of the U.S. and the other nations of the world will not be simple ones.

We believe that the free enterprise system can successfully meet the stiff challenge that faces the world. We need a government climate that provides support for efforts to develop alternatives coupled with clear guidance on the timing and stringency of any future regulations. We believe that the existing framework of laws is adequate to provide EPA with the authority that it needs to establish national goals and to participate in the international debate. However, we do not believe that EPA has the authority to levy a tax on CFC producers nor to auction to the highest bidder the rights to produce and consume CFCs. Such economic disincentive schemes would be counterproductive to the goal of a phase out of CFC production and use. In addition, we have serious doubts about whether the auction or fee schemes outlined by the OMB in the Fiscal '90 budget will raise the amount of revenue that the OMB projects.

We continue to believe that EPA can and must play a constructive role in the transition away from CFCs and into more acceptable alternatives. One role we have urged on EPA since 1986, when we and the Alliance for Responsible CFC Policy called for controls on CFC growth, is one of mediator in addition to its role as regulator. We urged EPA to undertake a regulatory negotiation with all interested parties at the table. This could take the form of a formal regulatory negotiation or informal consensus building leading to development of appropriate regulations. We understand that such efforts are frustrating for all parties because they take time and effort to come to a common understanding. However, we believe that this is such an important issue that the time and trouble are worth the effort.

We also believe that clear communication and cooperation by and between all relevant segments of our society, (industry, government, scientists, and environmental groups) must be fostered if we are to successfully accomplish the tasks that lie ahead. We have sought to engage in open communications as we determined how we should respond to the environmental effects of CFCs. We use several approaches to accomplish objective communication about the science, about industry's capability to respond, and about the policy choices involved in this issue. To illustrate one of these efforts, I am including, as Attachment C, several examples of a publication which we call *Fluorocarbon/Ozone Update.*

We have analyzed the task that lies ahead of us and believe, that for a successful transition to occur, we must continue to rely on fluorinated hydrocarbons as the principal alternatives to the CFCs. In our view, some of these alternatives will also need to contain chlorine, with low, but calculable, ozone depletion potential. We believe that such materials will allow the transition to be accomplished in an environmentally acceptable manner. To illustrate the basis for this last conclusion I am including as Attachment D, a graph from an EPA analysis showing the effect of a phase-out of CFCs and the phase-in of alternatives on the concentration of stratospheric chlorine. In this analysis EPA presented two scenarios. The top assumes that countries accounting for 90% of the global CFC use phase out of CFCs, and alternatives with an average of zero to two and a half percent (0.025%) of the ozone depletion potential of CFC 11 are used to replace current CFCs. Thus, in that case, if countries accounting for only 8% of current global CFC use do not comply with phase out, stratospheric chlorine will continue to rise. The bottom case is based on a complete phase-out of CFCs and the same mix of alternatives being employed to fill society's needs. The cases both assume a 65-year averaged growth rate of 2.8% in demand for goods and services currently using CFCs. As you can see, it is imperative that we achieve global cooperation in the phase-out of CFCs if we are to reduce stratospheric chlorine. In our judgment this will only be accomplished if the Montreal Protocol assessment mechanism is carried through to global agreement and implementation. We believe that this will only be done if affected industries have

the opportunity to make a transition to new technologies. We also believe that these technologies will need to rely on the use of the alternatives that we have identified.

Our approach to the phaseout of CFCs and the development of alternatives is comprehensive. We are developing conservation practices, material specifications and technology to assure that the CFCs that are being used are conserved and emissions are minimized. Where CFCs become spent in use and are unfit for continued use because of impurities, we are developing technology and infrastructure to reclaim them for reuse. This approach may not be not economic for all CFCs and all uses because of regulatory inhibitions.

As indicated above, we have identified alternatives for the major uses of CFCs that are distributed commercially. Based on our research and review of the literature and EPA findings, no other viable candidates are known. We have also studied the recent claims that certain non-halogenated alternatives and new technologies that do not rely on the identified fluorinated alternatives could be used for applications such as refrigeration and electronics cleaning. These technologies will find some use, but in our view they will not be practical nor widespread substitutes in the foreseeable future.

Having identified the most likely alternatives we scouted the chemistry necessary to produce them and, based on likely process routes, have begun to build and operate facilities to produce them on pilot scale and to obtain the needed basic data so that we can design and erect world scale plants. To date we have seven such plants in operation or under construction. These pilot facilities allow us to provide research and development quantities to our customers and to provide product to an international effort to assure their health and environmental safety. These international health and environmental studies are being accomplished through two programs under which many of the world's manufacturers, including Allied Signal Corporation a member of this panel of witnesses, have agreed to jointly fund toxicity testing. A third program to study the ozone depletion potential and greenhouse warming potentials of the leading alternative candidates is also underway. We believe that these efforts are unique because we and the other participants are not only developing the technology to produce the alternatives but are also developing the data needed to assure the safety and environmental acceptability of the alternative chemicals under consideration. The participants have pledged to publish the results of the studies once they are completed. We have kept the governments of the world advised of this work and our letter notifying EPA of the formation of the first groups is included in Attachment E.

Yet another segment of our phase-out program is to work with equipment designers to develop retrofit technologies so that existing, installed equipment can be used with substitutes as they become available. We believe that this is an essential element in any CFC phase-out strategy in view of the need to productively use this installed equipment. This is especially critical in view of the lack of manufacturing capacity to make enough new equipment in any reasonable timeframe for the many uses for which the CFCs are involved.

I would like to illustrate the magnitude of the replacement effort if retrofit technology is not developed promptly. There are about 120,000 large centrifugal chillers in the world with about 100,000 of them in the U.S. They range in size from 200 tons to several thousand tons capacity and hold from 500 to about 10,000 pounds or more of refrigerant 11 or 12. These units provide air conditioning for large buildings such as hospitals or office buildings and they provide refrigeration for industry. The cost of these units ranges from $500,000 to $2 million. At Du Pont, the typical unit is approximately of 1,000 ton capacity and represents an investment of $1 million in installed cost. Some of these units are approaching 50 years old and are still operating efficiently. There is global capacity to build less than 5,000 of these units per year. Thus, if we assume that sufficient quantities of an alternative were available today and no new office buidlings, no new apartment complexes and no new industrial plants would be built during the transition it would take more than 20 years just to build enough units to replace current units operating in the U.S.

In view of the cost of these large scale units and their long useful life, purchasers are in a dilemma in view of the uncertain future of for CFCs and the present unavailability of retrofit technology.

The Du Pont Company has about 350 such units. Thus, we consider it essential that retrofitting existing large scale units be an integral part of any phase out strategy and we are working with our equipment vendors to make it happen. The best candidate to replace CFC-11 in the most energy efficient centrifugal chillers, is HCFC-123. We are operating a pilot plant to develop basic data for design of commerical HCFC-123 manufacturing facilities, and are producing million pound per

year market development quantities of HCFC-123 in our plants in Europe and Japan.

We have converted two of our industrial CFC-11 chillers to use HCFC-123. Operating performance is satisfactory, although we have observed a capacity loss of about 15% which we expect to correct through a modification to the compressor at a cost estimated to be about $50,000. We are planning a retrofit test of a CFC-12 unit with HFC-134a later this year. We plan to share our experience when our work is complete, and to modify our units as the retrofit technology is developed.

This type of effort should also be encouraged within the Federal Government since it owns or leases about 455,000 buildings, most of which are air conditioned and use large chillers. This committee could propose a initiative to develop demonstration programs to develop and demonstrate alternative technologies. NIST, DOE, and other relevant agencies should be required to develop programs under which the government would lead the phaseout of CFC use. This subcommittee and others should then maintain oversight over government phaseout efforts to assure that they progress as fast as possible.

We also have a broad ranging program to develop alternatives for all of the major markets served by CFCs today. The status of this effort was recently discussed with the United Nations Environment Programme. I attach a copy of a presentation entitled "North American Application Experience with Substitute Chemicals, Producer Perspective" presented by Charles A. McCain on October 20, 1988. (See Attachment F).

In this testimony I would like to comment specifically on the Refrigeration, Air Conditioning segment of the CFC market. Please refer to Attachment G, which is a pie chart of the distribution of the U.S. refrigerant market by product.

Approximately sixty percent of the U.S. market for refrigerants is served by CFCs 11, 12 and specialty CFCs such as 113, 114, and 115. The remaining 40% is served by refrigerant 22, a hydrochlorofluorocarbon (HCFC) which we regard to be a desirable alternative. HCFC-22 possesses only 5% of the calculated ozone depletion potential of CFC-11.

Refer to the lower part of the chart (green portion) which shows the market share served by refrigerant 12. CFC-12 serves 50% of the refrigerant market for use in automobile air conditioners, commercial refrigeration and air conditioning, home refrigerators and freezers, and supermarket refrigeration. Only 16% of the market for CFC-12 is used to fill new equipment. The largest segment is auto air conditioners which use about 100 million pounds per year.

Eighty-four percent of the use for CFC-12 is to service the large inventory of refrigeration and air conditioning equipment which requires periodic replacement of its refrigerants throughout its useful life of 8 to 40 years.

We are working with the equipment manufacturers to provide candidate refrigerants and needed thermodynamic property data needed for redesign of their products. We believe the alternative HFC-134a will find application in some, but not all, of the new equipment designs. It has the desirable feature of zero ozone depletion potential because it contains no chlorine. We are operating two small plants to produce market development quantities, and product for toxicity testing. We are also building a commercial scale plant which is scheduled for startup in late 1990. Based on the lead time needed by equipment manufacturers to design and retool for changes in equipment, there will be virtually no commercial market for this product. However, we believe that our commitment and the assurance that HFC-134a will be available in commercial quantities will stimulate the design of new equipment to use our product so that the further phase-down required in 1993 can be accomplished with reduced impact on our economy. Although we and the users have not overcome all of the substantial technical hurdles that need to be overcome before this product is in widespread commercial use, I am confident that they will be overcome.

The greater challenge for the short term is the service segment of the market which consumes almost 200 million pounds per year, half to service auto air conditioners. We have explored numerous possibilities to offer a product to substitute for CFC-12 in this use and have recently discovered that certain blends of substances, which are still in the developmental stage, which we believe could serve most of this market segment. The most promising blend has only 2% of the ozone depletion potential of CFC-11. (A copy of our announcement of these blends is included as Attachment H). However, even this so-called "drop in" substitute will require modifications to the design of the air conditioners. If our assessment is confirmed by the Country's automakers, they could begin to develop air conditioner units that will operate on either currently available CFC-12 or the new blend when inadequate CFC-12 is available for servicing.

We project that commercial introduction of the best blend will be 4 to 5 years in the future because one of its components, HCFC-124, is not on the TSCA inventory and additional toxicity testing may be required to satisfy EPA prior to its commercial manufacture.

In the meantime, we have made available a transition blend product, which operates like our blend containing HCFC-124, and which reduces the level of ozone depletion potential by 60% compared to CFC-12. Adoption of this blend requires the same minor retrofits to air conditioner design as our preferred bland. However, much work still remains to be done to assure commercial viability of these new blends.

The task that lies ahead of us is daunting and as indicated in the above examples, we believe that the HCFCs are a part of the solution that will be needed if we are to protect stratospheric ozone. As a result, I am dismayed by the suggestions of some environmentalists and members of Congress that HCFC-22, which serves 40% of the market be regulated or even banned. It is used in millions of home window air conditioners and residential heat pumps. It has an ozone depletion potential of only 5% of CFC-11. In fact, if all the chlorine in the atmosphere were carried by HCFC-22 only there would be no Antarctic ozone hole.

A feature of all the HCFCs is their relative instability as compared to CFCs so that they decompose to a greater extent in the troposphere and less chlorine is carried into the stratosphere.

We know of no viable substitute for HCFC-22.

Thus, this threat of a phase-out of HCFC-22 is a threat not only for it but also for the entire HCFC family of alternatives we have identified. The threat of banning or severely restricting HCFC-22 in the future will delay if not prevent the introduction of most of the alternatives that I have discussed today.

Refrigeration and air conditioning comprises about 40% of the U.S. market for CFCs with the bulk of these being used to fill existing equipment. CFCs (30%) and the rest (10%) being used to fill new equipment.

The leading refrigeration candidates are HCF-134a, HCFC-123, and HCFC-22. HCFC-22 has been used for decades, but it can not easily be adopted to all applications. We currently produce HCFC-22 in world scale plants and have pilot facilities producing the other two. Our research indicates that each of these materials can be used in applications that now use either CFC-11 or CFC-12. We also expect that the National Institute of Standards and Technology (NIST) will be issuing refined thermodynamic property information that equipment designers can use. Although we have identified the compounds and are supplying samples for testing by our customers, we know that existing equipment will not operate reliably and without a loss in efficiency on these new compounds. Therefore, equipment manufacturers will need the time to design and test equipment that can operate reliably with one of the selected alternatives. This will involve both retrofit technology as well as new units.

The program I have outlined above is a costly one. We have spent nearly $70 million to date and will accelerate the rate of spending in 1989 to $45 million for research and development alone. If our products find acceptance in the marketplace, we will need to invest more than $1 billion in the United States alone over the next ten years to build new manufacturing facilities or modify existing ones. Part of this investment will be required before we are sure of commercial success if we are to reach our goal of a phase out of U.S. production by the turn of the century. We are committed to do just that so long as the regulatory climate and business climate is favorable to the long term success of these alternatives.

If the pace of the phaseout is accelerated beyond that which is called for in the Montreal protocol, or if alternatives are not adopted for new applications by the mid-1990s, thereby reserving the allowable CFCs for use in existing equipment, major disruptions in our economy are likely to occur. For example, there could be lapses in the supply of blood and medical supplies and unacceptable spoilage in our food supply. Insufficient supplies of fluid would be available to service mobile air conditioning equipment, not only in personal autos but also in public transportation applications. This would result not only in discomfort, but to sensitive groups in our population, could prove life threatening. It could also contribute to driver fatigue and could raise accident rates.

We have been discussing the issue as though the only substitutes that are viable on a widespread basis are those which we have identified. To be sure there are substitutes available for some uses. For example in refrigeration applications materials like sulfur dioxide, ammonia and propane can be used. In fact in some industrial applications they now find limited use. However, the problems in bringing to market technology which utilizes them would be nearly impossible to apply in the needed time frame. In addition, we would be concerned with the hazards that they

pose in situations where they were not operated by well trained operators, or where releases could result in unacceptable human exposures.

We and a number of our competitors are doing everything we can to be in a position to supply the alternatives to the market as soon as possible. Equipment manufacturers are doing essential design work and are beginning performance testing needed to assure quality and reliability of their products. As discussed above, we have begun the conversion of large chillers to obtain data on the feasibility of retrofitting these units to use the identified alternatives. We would hope that this subcommittee could encourage similar actions by the Federal government to induce a more rapid transition from CFCs.

One of the barriers that we are encountering in obtaining customer commitment to the alternatives that we have identified is the climate of regulatory uncertainty, The government, and that includes the Congress needs to remove the cloud of an uncertain future for the HCFCs. We have analyzed their potential chlorine contribution to the stratosphere and believe that there is a sufficient safety margin even if they grow at a rate of 2.8% per year after all current uses of CFCs are satisfied. Industry does not need assurance of perpetual availability, but it does need assurance that a reasonable life cycle for these alternatives can be assured if we are to invest the needed capital to make it happen.

In addition, we have reviewed the process technology and basic on data developed to date, we are confident that the switch to new processes and chemistry for production of the alternatives will result in no increase in either the type or amount of emissions, to air, water or in our waste than current technology. Our process development engineers have been given this charge and they are developing processes that either eliminate waste streams by assuring that reaction products are useful or by using technology that does not allow releases.

The U.S. also needs to continue to send a strong signal that an international agreement on control and phase out strategies is essential to protection of stratospheric ozone. We do not believe we should repeat the 1978 decision to unilaterally ban aerosols. The result of that action was to give other countries the impression that we had solved the problem and their actions need not be as stringent. The net result was that the U.S. lost 20% of global market share for CFCs. It also meant that other major producing countries did not reduce nonessential uses and now need not reduce essential uses. Outside of the U.S., most of the cutbacks called for by the Montreal Protocol can be accommodated by elimination of aerosol applications.

We believe that this Subcommittee needs to increase appropriations for NIST work that is needed to provide basic data on the properties of the alternatives. In addition, the contribution of scientists such as participated in the fist panel today need to be recognized and their work supported. We believe that it will continue to be important that the study of the stratosphere continues.

We believe that the MIL specs for electronics cleaning agents need to be modified or applications critical to national defense may not be met. In general the regulatory and defense agencies need to address issue surrounding approvals for substitutes with urgency. We are not asking that the standards be lowered, but we are asking that reviews and decisions be made promptly. For example, 50% of the CFC-113 that is used in the manufacture of electronic components go directly or indirectly into military applications. Alternatives need to be evaluated promptly, or government contractors may be unable to supply components needed for the national security.

As discussed above, a switch to non-CFC equipment is needed by the mid-1990s or as soon thereafter as possible to assure that the environmental goals of the country can be met, while at the same time existing CFC using equipment can be used for as long as possible. It is necessary for EPA, DOE and other interested agencies to establish a dialog involving all necessary parties to address the knotty issues that face us. Such dialog will also give our negotiators in international negotiations needed information to forge rational and fair modifications to the phase-down schedule of the Montreal Protocol.

Capital requirements for all CFC producers worldwide to restructure their businesses could total $6 billion over the next decade. While this amount is significant, it may pale in comparison to the capital requirements of industries which produce refrigeration, air conditioning, and cleaning equipment, as well as insulation and plastic foam products.

We need to successfully engage in this restructuring to maintain our global competitiveness as a nation and as an industry.

In closing, I would like to outline some of the barriers to an orderly transition to a total phase out of CFCs by the turn of the century. They are:

Incomplete basic data for design of world scale plants capable of high yields at favorable investment and operating costs.

Lack of complete toxicity profiles for all of the alternative candidates.

Incomplete or inconsistent thermodynamic and transport property information on all of the identified alternatives.

Incomplete development of equipment that can use the alternatives.

Signals at EPA and in the halls of Congress that some of the identified alternatives will have insufficient product lifetimes to justify the investment needed for us to produce them and for our customers to develop equipment to use them.

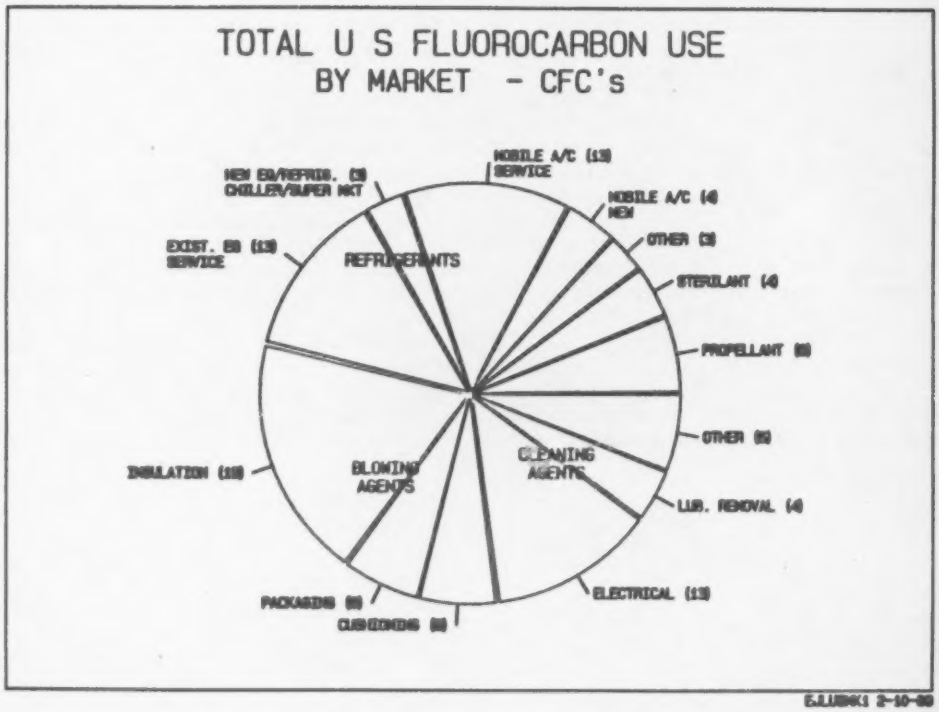
High capital needs and an uncertain business climate.

Threats in the U.S. of auctions or taxes that will divert needed revenue streams from the private sector to the government's general fund.

The need to complete development, evaluation and design of retrofit technologies to the current equipment which relies on CFCs (U.S. investment alone exceeds $135 billion) will serve for its useful life.

Unless we can build on the knowledge that we have developed to date and overcome the hurdles that I have outlines above, we will see significant economic and social impact as CFCs are phased out. I trust that my testimony will be of assistance in guiding you as you develop policy for addressing the knotty issues that face us.

Thank you for your attention.



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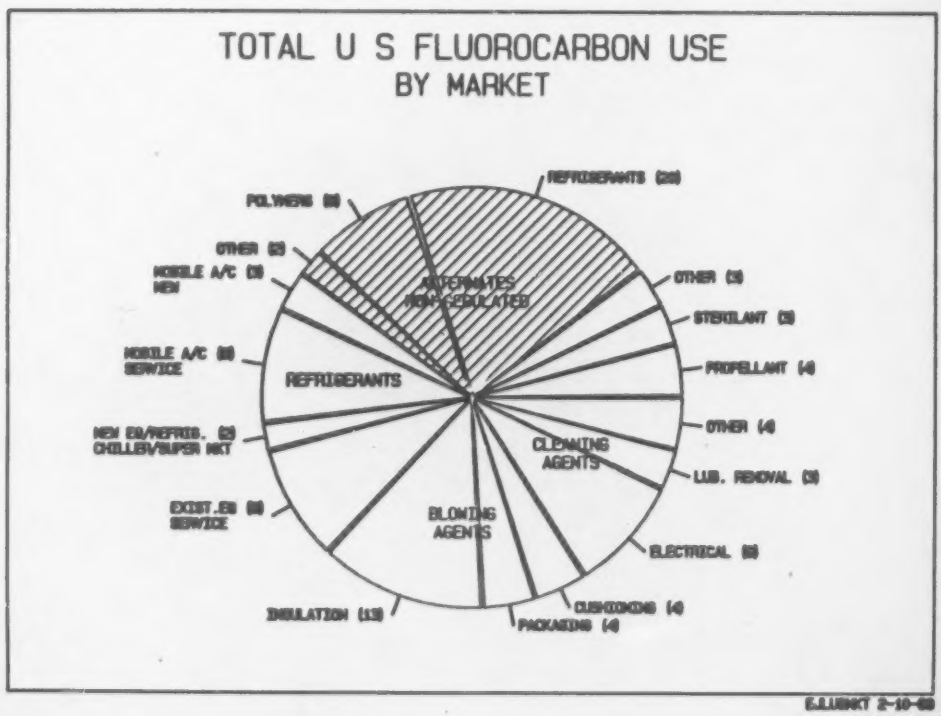
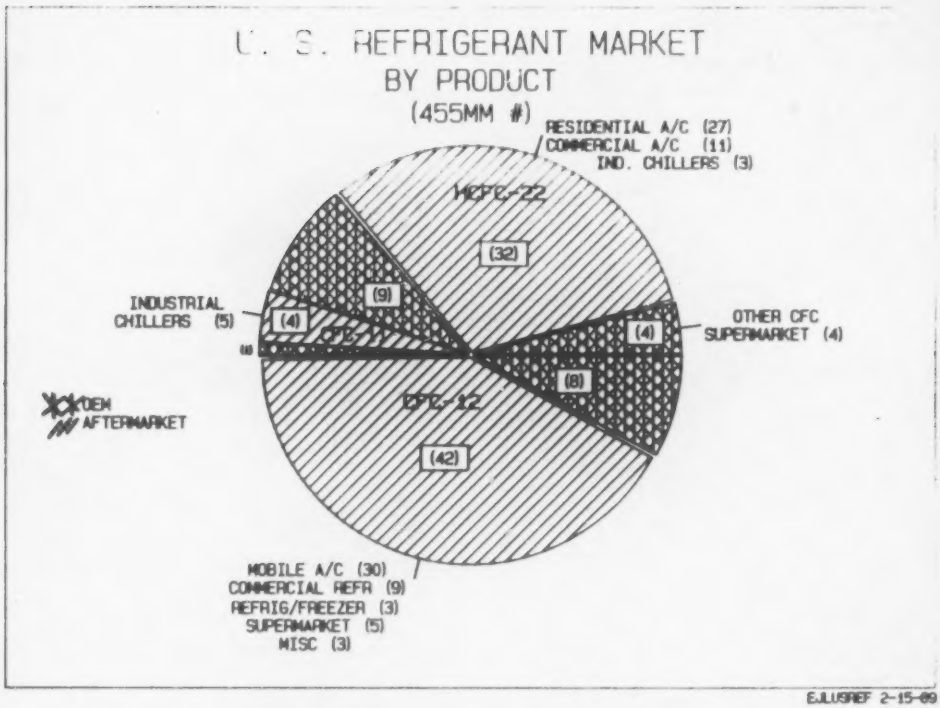
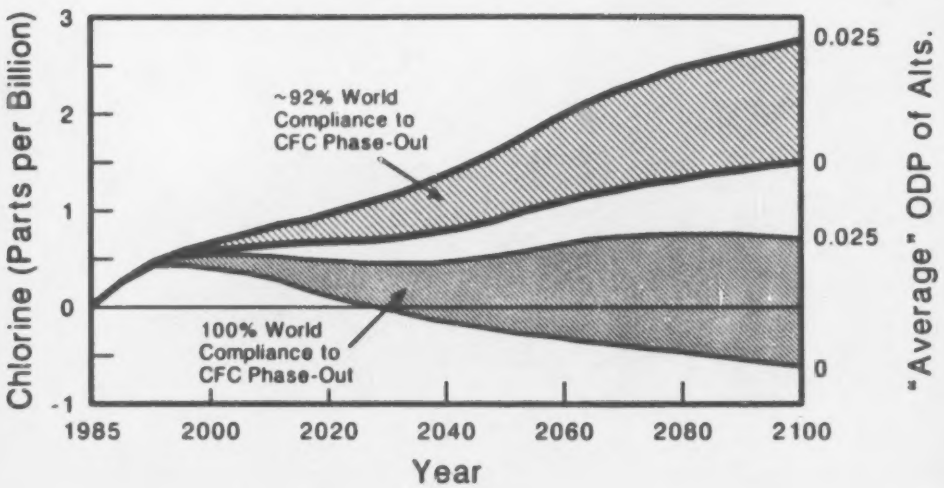


E.LUBK2 2-10-88



Importance of Alternatives

Calculated Change in Stratospheric Chlorine



Base Assumption: 2.8%/ Yr Growth 1985-2050

Source: Data from Exhibit 23, p. 51 of "Future Concentrations of Stratospheric Chlorine and Bromine," EPA Report 400/ 1-88/ 005 by J. S. Hoffman and M. J. Gibbs.

Products Made With or Containing Chlorofluorocarbons

RIGID FOAM	MADE WITH	CONTAINS OR USES
- automotive door panel padding		●
- boat hull void filler		●
- building steel fire protection		●
- buoy, dock protection foam padding		●
- crack or crevice filler		●
- disposable dishes		●
- egg cartons		●
- extruded polystyrene insulating foam		●
- fast food "clam shell" package		●
- foam drinking cups		●
- foam ice chests		●
- foam in place urethane packaging (computers)		●
- foam packing cushion chips		●
- foundation/basement insulating sheets		●
- freezer insulation		●
- home insulating sheathing		●
- refrigerated truck insulation		●
- refrigerator insulation		●
- rigid pipe insulation		●
- roof insulation		●
- storage tank insulation		●
- styrofoam		●
- supermarket meat trays		●
- tank car insulation		●
FLEXIBLE FOAM		
- automobile dashboards	●	
- automobile seat cushions	●	
- bedding foam pillows and mattresses	●	
- bicycle seats	●	
- carpet pads	●	
- coaxial cable	●	
- flexible pipe insulation	●	
- furniture cushions	●	
- furniture protective wrapping	●	
- motorcycle seats	●	
- packaging cushions	●	
- postal mailers	●	
- soft toy stuffing	●	
- sports cushioning or pads	●	
- vibration dampeners	●	
REFRIGERATION AND AIR CONDITIONING		
- agricultural food chiller		●
- aircraft air conditioning		●
- auto air conditioners		●
- beer dispensers		●
- bus air conditioning		●
- cold storage warehouses		●

Refrigeration and Air Conditioning (cont'd)	MADE WITH	CONTAINS OR USES
- commercial fishing boat refrigeration		●
- dehumidifiers		●
- grocery store freezers		●
- grocery store refrigerators		●
- home air conditioners, central and window units		●
- home freezers		●
- home heat pumps		●
- home refrigerators		●
- ice machines		●
- mall air conditioning		●
- office building chillers		●
- process industry refrigeration, heat recovery		●
- refrigerated storage		●
- refrigerated transport trucks, rail cars		●
- rooftop and office building air conditioners		●
- soda fountain dispensers		●
- soft ice cream or yogurt machines		●
- store air conditioning		●
- train air conditioning		●
- truck air conditioning		●
- vending machines		●
- warehouse air conditioning		●
- water coolers/fountains		●
MISCELLANEOUS		
- aerosol cleaners where exempted		●
- aerosol insecticides where exempted		●
- aircraft fire extinguisher systems		●
- pipeline pumping station fire extinguishers		●
- aluminum impurity removal	●	
- blood plasma	●	
- bronchial inhalant medications		●
- chewing gum remover		●
- computer disc envelopes	●	
- computer room fire extinguishers		●
- dusters for cameras		●
- electric transformer dielectric fluid		●
- flash spun polyethylene sheet	●	
- gum remover		●
- hemorrhoidal foam		●
- hospital sterilization		●
- immersion food freezing	●	
- insecticides for agricultural applications		●
- insecticides for commercial food preparation areas		●

	MADE WITH	CONTAINS OR USES
Miscellaneous (cont'd)		
- insecticides for government use		•
- low tar tobacco	•	
- marine horns and sirens		•
- medical apparatus syringes, surgical tubing	•	
- medical sterile packaging	•	
- military aerosols where exempted		•
- mold release agents dispersant		•
- molded plastic parts	•	
- oil exploration fire protection		•
- nuclear power plant control room fire extinguishers		•
- polyolefin concrete reinforcement	•	
- polyolefin envelopes for "Federal Express"/military mail	•	
- polyolefin filter elements	•	
- polyolefin garments for toxics cleanup	•	
- portable fire extinguishers		•
- race car fire extinguishers systems		•
- skin sterilant used prior to surgery		•
- space craft propellant	•	
- spices	•	
- urethane sole shoes		•
- weld inspection dye and developer		•
ELECTRONICS, CLEANING AGENTS		
- air conditioner condenser coils	•	
- air conditioner evaporator coils	•	
- aircraft sheet metal assemblies	•	
- artificial hip joints	•	
- artificial limbs, implants	•	
- automotive electronic components	•	
- ball bearings		•
- calculators	•	
- cameras	•	
- cardiac pace makers	•	
- catheters	•	
- chemical warfare decontamination fluids		•
- clothes dryers	•	
- clothes washers	•	
- computer disc memory storage components	•	
- computers	•	
- contact lenses	•	

	MADE WITH	CONTAINS OR USES
Electronics, cleaning agents (cont'd)		
- coolant systems for infrared sensing missiles		•
- coolant systems for space shuttles		•
- dielectric fluids for radar and microwave communications		•
- electric and electronic toys	•	
- electric transmission transformers	•	
- electro-mechanical controls	•	
- electronic switches	•	
- fluorinated polymer seal materials		•
- garment drycleaning fluid	•	
- home heating thermostats	•	
- hospital oxygen systems	•	
- hydraulic controls	•	
- hydraulic systems for civilian, military and space craft	•	
- jewelry	•	
- kidney dialysis capillaries	•	
- kitchen dishwashers	•	
- lenses for glasses	•	
- microwave ovens	•	
- nuclear reactor vessels	•	
- photocopiers	•	
- plasma etchant and desmearing gases	•	
- plastic auto body parts	•	
- plastic mold release fluids	•	
- plated metal and plastic parts	•	
- printed circuit boards	•	
- radioactive decontamination		•
- radios	•	
- rifle scopes	•	
- satellite, airplane, naval inertial guidance gyroscopes	•	
- semiconductors	•	
- silicon wafers	•	
- smoke alarms	•	
- telephone CBX systems	•	
- telephones	•	
- televisions	•	
- tetraoxide fuel systems for space program	•	
- textile fabric garments	•	
- thermal bulbs for temperature controllers	•	
- thermostats	•	
- typewriters	•	
- VCR's	•	

TABLE 1
MAJOR COMMERCIAL CHLOROFLUOROCARBONS

NUMBER	FORMULA	B.P. °C	REFRIGERANT	BLOWING AGENT	CLEANING AGENT	OTHER (a)	OZONE DEPLE. POTEN. (e)	GREENHOUSE POTENTIAL (f)
CFC-11	CCl_3F	23.8	Yes	Yes	Limited	-	1.0	0.4
-12	CCl_2F_2	-29.8	Yes (b)	Yes	-	(c)	0.9	1.0
-113	CCl_2FCClF_2	47.6	Yes	Yes	Yes	-	0.8	.3 to .8(g)
-114	$CClF_2CClF_2$	3.6	Yes	Yes	-	-	0.6	.5 to 1.5(g)
-115	$CClF_2CF_3$	-38.7	Yes (b)	Limited	-	-	0.3	1 to 3(g)
Halon 1301	$CBrF_3$	-57.8	Limited	-	-	(d)	~10 (Estimate)	0.8

(a) Excludes minor uses not discussed in this update
(b) Also component of refrigerant azeotropic mixtures
(c) Direct contact liquid food freezant and inerting agent for ethylene oxide sterilant gas
(d) Fire extinguishant (Halon 1301)
(e) Compared to CFC-11 with a value of 1.0 on a per pound basis
(f) Compared to CFC-12 with a value of 1.0 on a per pound basis
(g) Estimated range. The data required for a complete analysis are not available

TABLE 2.—CHLOROFLUOROCARBON ALTERNATIVES

Number	Formula	B.P.° C	Potential application	Flammable	Manufacturing process	Toxicology	Ozone depletion potential [1] [2] [3]
Existing commercial products:							
FC–22	$CHClF_2$	−40.8	Refrigerant, blowing agent	No	Yes	Low	0.05
FC–142b	CH_3CClF_2	−9.2	Propellant	Yes	Yes	Low	.06
FC–152a	CH_3CHF_2	−24.7	Propellant refrigerant	Yes	Yes	Low	0
Under consideration:							
FC–123	$CHCl_2CF_3$	28.7	Blowing agent, refrigerant	No	CD [4]	Low [5]	.02
FC–124	$CHClFCF_3$	−12.0	Refrigerant, blowing agent	No	CD [4]	Low [5]	.02
FC–125	CHF_2CF_3	−48.5	Refrigerant	No	CD [4]	Incomplete	0
FC–134a	CH_2FCF_3	−26.5	Refrigerant	No	CD [4]	Incomplete	0
FC–141b	CH_3CCl_2F	32.0	Propellant blowing agent	Yes	Yes [4]	Incomplete	.10
FC–143a	CH_3CF_3	−47.6	Refrigerant	Yes	NC [6]	Incomplete	0
Disqualified toxic:							
FC–21	$CHCl_2F$	8.9	Blowing agent	No	Yes	Toxic [7]	.05
FC–31	CH_2ClF	−9.1	Propellant	Yes	NC [6]	Toxic [7]	.05
FC–133a	CH_2ClCF_3	6.1	Refrigerant	No	NC (US)	Embryotoxin [7]	.05
FC–132b	$CH_2ClCClF_2$	46.8	Cleaning agent	No	No	Toxic [7]	.05

[1] Compared to CFC–11 with a value of 1.
[2] Calculated global warming potentials are being determined by an international group of scientists and results will be reported by May meeting of UNEP parties to the Montreal protocol. Preliminary data indicate that the HFC's and HCFC's are an order of magnitude lower than the compounds they would replace.
[3] Ozone depletion values published in UNEP/OxL Sc. 1/14 add. 2/p. 2 (Oct. 18, 1988) meeting held in The Hague.
[4] Total commercial scale process not defined.
[5] Incomplete.
[6] NC—Not commercialized.
[7] Work discontinued principally for this reason.

[The following information was subsequently received for the record:]

DUPONT

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
WILMINGTON, DELAWARE 19898

CHEMICALS AND PIGMENTS DEPARTMENT

April 24, 1989

The Honorable Albert Gore, Jr.
United States Senate
SR-393 Russell Senate Office Building
Washington, D.C. 20510-4202

Dear Senator Gore:

Subsequent to my February 27 testimony before the Senate Subcommittee on Science, Technology and Space, you and the members of your committee posed 24 questions to Du Pont on the subject of CFC alternatives and their development. Our responses are attached.

To summarize briefly, Du Pont believes that alternatives in the fluorocarbon family -- the HCFCs and HFCs -- provide the best opportunity for a rapid transition away from CFCs. HCFCs and HFCs can meet the dual goals of environmental protection and performance approximating that of CFCs in critical applications such as refrigeration, air conditioning and energy-efficient insulation.

While these compounds appear to be promising alternatives, we may not be successful in commercializing them. Technical challenges and the possibility of regulation are the principal barriers. You and your colleagues can facilitate the introduction and adoption of the HCFCs and HFCs by providing assurances that these products will not be regulated, thus making possible normal life cycles. Also, the current budget proposal to charge a fee or auction CFC production would be counterproductive to the rapid phaseout of CFCs and transition to alternatives.

If we are unsuccessful in our alternatives development efforts, developing countries are likely to pursue the use of CFC technology to meet their needs. This would be counter-productive to protection of the environment.

After you and your staff have reviewed our responses, please feel free to contact me or our office if you have any additional questions.

I understand that you have been occupied by the recent injury to your son and hope that he has a full and speedy recovery.

Sincerely,

J. P. Glas

J. P. Glas, Director
Freon® Products Division

SENATOR GORE'S QUESTIONS

1. *What tests have you conducted which show that R-23 or R-32 could not be a substitute for HCFC-22 with equipment redesign? Please provide detailed data to back up your statement that "we know of no viable substitute for HCFC-22."*

   The attached vapor pressure curve and tabular information (attachments 1 & 2, respectively) show that R-23 and R-32 have much lower boiling points than R-22; hence they are not suited as R-22 replacements. These data show the substantial pressure increase necessary to operate a typical room air conditioner on R-23 or R-32. Also, because R-32 is flammable, it is probably unacceptable as a pure component refrigerant.

2. *Is Du Pont retracting its comment to some user groups that it plans to stop selling them CFC-11 or CFC-12 at a certain date?*

   Du Pont has continually stated its corporate position of commitment to develop alternatives as soon as technically possible, to work with customers to expedite their introduction, and to phase out CFCs as soon thereafter as possible, but no later than the turn of the century.

3. *Has Du Pont increased its shipments to Igloo for the purpose of stockpiling reported in the trade press and eliminated shipments to other aftermarket distributors for the auto markets?*

   Rephrase the question in two parts:

   a. *Has Du Pont increased its shipments to Igloo for the purpose of stockpiling?*

      No. If it appears to us that any customer is stockpiling, we will investigate and decline to supply if there is unusual stock inventory.

   b. *Has Du Pont eliminated shipments to other aftermarket distributors for the auto market?*

      Yes. Before EPA's CFC regulations were enacted, we restructured our approach to the automotive aftermarket by aligning ourselves with Igloo as our sole Freon® distributor to this market segment.

4. *How much has Du Pont raised the price of CFC 11, 12, 113, 114, 115 or blends among them? How much have you increased 1988 sales? How much have you increased HCFC-22 sales? How much have you raised the price of HCFC-22?*

Du Pont's average price for CFCs in 1988 was 5% higher than in 1987. This increase was insufficient to cover the 11% increase in costs due to higher materials and labor costs and accelerated spending on alternatives.

In 1989, costs and spending on alternatives will continue to increase. Reduced production to meet the regulatory cap will result in higher fixed costs per pound. Raw material costs will also increase beyond normal inflation rates as raw material suppliers are similarly impacted.

Increased customer service associated with emission reduction, recovery and recycle, and evaluation of new chemicals and technologies, will increase costs further, along with new costs associated with CFC regulation (record-keeping, reporting, etc.) and large R&D expenditures, currently estimated at $45 million in 1989. As a result, costs are expected to rise another 15 - 20% over 1988 levels. Price increases in 1989 are planned to cover this cost increase, recover margin lost in 1988, and to bring the business a sufficiently attractive return to justify needed investment.

Profitability from this business in 1988 was significantly below what one would expect from even a very low risk investment (i.e., Treasury Bonds) and certainly below what an investor would expect for the extremely high risk associated with alternatives development.

Sales volume of CFCs in 1988 was below 1987, reflecting early results of our efforts to convert CFC users to recently commercialized alternative products, such as Formacel® S blowing agent, a reformulation of HCFC-22 that has replaced CFC-12 in polystyrene food packaging. Market acceptance of Formacel® is part of the reason that Du Pont's 1988 HCFC-22 sales volume was 15% ahead of 1987. Another contributing factor was a 60% reduction in imported material.

In 1988, HCFC-22 prices continued a four-year historical decline through mid-year, resulting in a 5% drop from average 1987 to 1988. The four-year decline reduced realized prices a total of 20% while costs rose 14%. In the second half of 1988, sales volume approached industry capacity. If increased demands are to be met, industry must invest in new facilities. That investment cannot be justified if market prices do not rise to a level that attracts stockholder investments.

5. *You claimed you have done everything possible to introduce substitutes, yet so far you have not released all thermophysical data complied on the full range of substitutes you have investigated. How do you reconcile*

them and your statement? How soon will you release this vital information?

Du Pont released new thermophysical data through appropriate forums, such as ASHRAE (American Society of Heating, Refrigeration & Air-Conditioning Engineers, Inc.), as soon as that information was developed in suitable form.

6. *Why haven't you started 2-year inhalation studies of R-124 and R-125 if you believe these compounds can contribute to the solution?*

Du Pont and other producers conducted initial toxicity screens in the 1970s on both products. In addition, there was enough interest in R-124 in the 1970s to proceed with a teratology study and a 90-day inhalation test. Only the initial screening is complete on R-125. The final phase of testing, a 2-year chronic test, will require large quantities of product, which we estimate will be available in 1 to 2 years.

In an effort to accelerate the testing, we have proposed a third industry toxicity testing effort to sponsor the next phase of testing of HCFC-124 and HFC-125. This will lead to initiation of the 2-year tests. Several companies have expressed interest in the consortium, and we expect agreement on the program by June 1, 1989, with public announcement by June 15, 1989 .

Neither of these compounds is TSCA listed, but we have filed a premanufacturing notice (PMN) with the EPA for HCFC-124. Until EPA's concerns about toxicity are resolved, control measures being proposed by EPA will preclude rapid progress with the development of HCFC-124. Under current plans, we hope to have sufficient product to begin 2-year chronic exposure tests by 1991.

7. *Why don't Du Pont and other chemical companies agree on a crash program of thermophysical testing*

Such a program is a key priority of the Air-Conditioning & Refrigeration Institute (ARI), Research and Technology Committee, which Du Pont, other producers and the users are supporting.

SENATOR HOLLINGS' QUESTIONS

8. *Any comprehensive strategy to cut CFC emissions will require developing CFC alternatives, developing new technology, and instituting CFC recycling programs.*

a. Which steps do you think will yield the largest reduction in emissions most quickly and for the least effort?

We believe stringency, i.e., a total phaseout, is far more important than aggressive steps to achieve short-term reductions. Therefore, modifying the design of refrigerators, freezers, air conditioners, cleaning equipment and polymer foam products so that they do not require CFCs should receive first priority. As a result, the user industry can stop building equipment dependent upon CFCs for its useful life. Retrofit technology for existing equipment ($135 billion invested in the U.S.) ranks a close second.

The government has a huge investment stake as the largest owner and leaseholder of air conditioned building space in the U.S. We recommend more aggressive government action to retrofit its facilities and provide leadership to the nation. Implementation of design features for new equipment that reduce losses during operation or servicing could help in conservation, recovery, and recycle of refrigerants for industrial equipment. It is likely that each major industry segment could suggest "best practice" design features that their industries would support.

Recycling and capture of CFCs from existing equipment should be carefully studied, and a national set of guidelines established. Because of the tremendous difference in CFC applications, it is necessary that considerable thought be given to this task so that the effort provides significant environmental value and is not just a cost burden to society.

b. Are there federal laws and regulations that are making cutting CFC emissions more difficult?

When EPA promulgated their stratospheric ozone protection regulation on April 12, 1988, they did not preempt state action to go beyond the protocol. At this time, there are roughly 50 proposed CFC bans or restrictions proposed by 18 states. While these proposals are all well meaning, they disrupt the orderly transition from CFCs to alternates on a national scale -- the necessary approach to assure global protection of the ozone layer.

The great majority and perhaps all of the states have policies and restrictions designed to reduce ambient concentrations of Volatile Organic Chemicals. In general, those restrictions apply to materials that can be used as substitutes for CFCs, such as hydrocarbons, even if these substitutes do not significantly

contribute to formation of ambient ozone. These restrictions can result in the unavailability of permits to use new materials, can require the installation and operation of expensive technology to reduce emissions, or delay the necessary permitting process. In practice, the restrictions pose formidable barriers to use of substitutes.

Existing federal and related state regulatory regimes, which are not always consistent, impose (or because of ambiguities are regarded as imposing) substantial regulatory burdens and barriers to economic recycling of CFCs and to disposal of CFCs as wastes.

The rash of congressional activity suggesting inclusion of HCFCs in the regulatory process for protecting stratospheric ozone is counterproductive.

- Classing HCFCs similar to CFCs or Halons would raise serious doubts for investors in CFC-producing and using industries.

- Inclusion in the Protocol and implied future production limits raises the specter of the market out-pacing capacity and an allocation of production rights, not just within a country, but between countries.

- Many environmental regulations have led to an ultimate ban on a product, a difficult climate for supporting huge capital investments.

Not-in-kind materials will not be able to replace CFCs in many markets or applications; therefore, rejection of HCFCs would require identification and development of entirely new technologies, thus resulting in worldwide dependence on CFCs for several additional years.

The world manufacturing and technical base cannot replace much of the existing CFC-using equipment rapidly. So, it must be kept operating, either by continued use of CFCs or by converting to HCFCs and HFCs.

Costs to meet society's basic needs without CFCs may not be an insurmountable hurdle in the U.S. or other countries. However, it will be a critical factor in the developing countries' decision to phase-out CFCs.

9. ***The federal government spends millions of dollars a year funding R&D on replacing CFCs. One program at the National Institute of Standards and Technology which evaluates CFC alternatives was recently expanded.***

a. Have such programs been useful?

b. In your opinion, which of these programs should the Congress consider expanding?

CFC alternative R&D programs at NIST and Oak Ridge National Laboratories have been useful. NIST is the world-recognized leader in thermophysical property measurements, and they are providing valuable data for CFC alternatives, resolving differences in data reported by several CFC producers. NIST personnel have several years' experience in the theoretical and applied aspects of refrigeration heat transfer, and these capabilities could be useful in applications testing of CFC alternatives. This would lead to optimization of energy efficiency.

Oak Ridge National Laboratory personnel have a strong background in heat pump and thermal insulation R&D, and have recently expanded their R&D to testing of refrigerants and lubricants in calorimeters and home refrigerators. All of the ORNL programs are focusing on improvement of energy efficiency, and are viewed as essential by the CFC applications industries.

In our opinion, these organizations have good working relations with industry and their capabilities should be fully utilized.

10. *Dr. Watson mentioned that the concentration of carbon tetrachloride in the atmosphere is increasing more than 1% per year. While carbon tetrachloride is not a CFC it does cause ozone depletion. Yet scientists have not been able to identify the sources responsible for this increase.*

a. If you had to guess, who would you blame for the increasing amount of carbon tetrachloride in our atmosphere?

b. How much carbon tetrachloride is produced in the United States each year?

Since Du Pont does not manufacture CCl_4, Du Pont is not the best source of information. The U.S. producers of CCl_4 are Dow, Vulcan and AKZO. They probably have better information.

We have good measurements at our CCl_4 using sites that produce CFC-11 and CFC-12, and our fugitive emissions are well below 0.1% of our CCl_4 use.

Years ago, U.S. industries used CCl_4 for grain fumigation and metal degreasing; it is possible that other nations use CCl_4 in this way.

Inclusion of CCl_4 in the Montreal Protocol may be a way to gain better global information on this compound.

11. *The production processes for CFC alternatives are much more complicated than the simple processes used to make most CFCs.*

a. How much more expensive will CFC alternatives be?

At this point in the development cycle, we estimate that the substitutes we are developing (from the fluorocarbon family, HCFCs and HFC's) will cost 1-1/2 to 5 times more than CFCs they would replace. When initially introduced, the costs of alternatives will be higher until processes are optimized.

In 1972 the Boston Consulting Group in a book entitled "Perspectives on Experience" presented an empirical method of price forecasting called the experience curve method. The method is based on observations that the costs of production and marketing decline as an industry gains experience; i.e.,

- o labor learns their jobs more rapidly,
- o successful producers build bigger plants and improve economies of scale, and
- o marketing becomes more efficient.

Mathematically, the consulting group found that product unit costs (in constant dollars) drop 20 to 30% for each doubling of cumulative volume. This observation has been shown to be accurate for many different products in many different industries. The method's accuracy declines if free market forces are distorted by such events as a shortage or glut in raw materials, an interfering government action, or a strong, worldwide patent position.

The available price/volume data for CFC-12 fits the experience curve well through the period 1958 to 1973 except around the time of the United States aerosol ban and the Arab oil embargo. CFC-12 price declines almost exactly 30% for each doubling of cumulative volume, as predicted by the experience curve model up through the 15 billion pounds of total world production by 1980.

Using the CFC-12 curve as a basis, an experience curve was constructed for hydrofluorocarbon 134a (HFC-134a), the leading alternate refrigerant candidate for CFC-12. We assumed the slope of the curves to be equal, assuming that the worldwide industry will learn to make HFC-134a at the same rate as CFC-12. (The experience curve model

tells us that the industry has been very efficient at improving CFC-12 manufacture at the limiting 30% "slope" point versus the range of 20 to 30%, and we probably shouldn't expect much faster improvement for HFC-134a if it is like all other products.)

Based on the experience curve, the first 100 thousand lbs. of HFC-134a would sell for $75/lb. After 1 million lbs., the price would drop to $30/lb. At 10 million lbs./yr. (40 million lbs. cumulative volume) the price would be about $7.50/lb, and at 100 million lbs./yr., a volume which might be achieved by 2000, the price would be about $3.00/lb.

b. *Will production of CFC alternatives lead to dangerous by-products which will be difficult to dispose of?*

To assure that we have cost effective processes that make high quality products, we have spent the resources to develop technology that is highly selective in converting raw materials to the desired products. We have a corporate policy of "internalization of wastes" and expect unintentional by-products or wastes to be comparable or less than that produced in existing CFC plants.

c. *Will CFCs be produced as part of the production process?*

Our proposed alternate technologies will not produce undesired CFCs that require disposal. It should be noted that FC-116 is a current product made from CFCs 113, 114, or 115. The Montreal Protocol has provision to "transform" CFCs as a feedstock or intermediate to desired non-CFC products.

d. *Are many of the problems you've mentioned inherent in the process, or will they be worked out as you perfect your production techniques?*

Higher cost of the substitutes is inherent in the chemistry and complex processes. We expect costs will improve with experience, and as volume increases. However, experience will bring down costs to the 1-1/2 to 5 factor previously mentioned. Costs from initial facilities will exceed these factors.

12. *While carbon dioxide is the largest contributor to greenhouse warming, CFCs are responsible for about a fifth of the problem. Many of the replacements for CFCs are also greenhouse gases.*

a. Are they better or worse than CFCs in this respect?

Because the compounds being evaluated as replacements are decomposed in the lower part of the atmosphere, they have much lower global warming potentials than CFCs. These compounds will probably reduce global warming due to CFCs by about 90%.

b. Would you be hesitant to go into production of a CFC replacement that was a worse greenhouse gas than the CFCs they replace?

Yes. In fact, we would not do it.

13. *It is clear that an international effort will be needed if we're going to make the necessary cuts in CFC emissions. There is now a great deal of discussion about cuts which are deeper and faster than those in the Montreal Protocol.*

a. Which countries do you see as being most reluctant to go along with deeper cuts?

We do not have that information. The State Department may be a better source.

Du Pont believes that developed nations must send very positive signals that they will supply CFCs to developing countries for the time period permitted by the Protocol. This would assure that those nations do not build CFC plants before alternates are available.

b. In general, have U.S. companies been more willing than foreign firms to accept the need for CFC production cuts?

In all regions of the world, we see a growing recognition by our customers of the need for phaseout, but considerable concern about achievability of rapid phaseout schedules. The U.S. State Department and EPA staff could provide a well-balanced assessment of global response based on its contacts with world government policy-makers and regulators.

SENATOR PRESSLER'S QUESTIONS

Are CFC substitutes safe? Some substitutes are only 5% as destructive as the current chemicals. Is 5% too high? Can you do better, and, if so, at what cost?

Du Pont has identified nine candidate products as potential CFC substitutes. These products have the following ozone depletion potential (ODPs):

	BOILING POINT	ODP
HCFC-22	- 41°C	0.05
HCFC-123	28°C	0.02
HCFC-124	- 11°C	0.02
HCFC-141b	32°C	0.10
HCFC-142b	- 9°C	0.06
HFC-125	- 48°C	0.0
HFC-143a	- 48°C	0.0
HFC-134a	- 27°C	0.0
HFC-152a	- 25°C	0.0

There are no zero ozone depletion compounds with boiling points near CFC-11 (25°C) and CFC-113 (48°C). The development of any new candidates with zero ozone depletion potential would require industry to develop completely new processes and technologies - an exercise that typically takes about fifteen years.

Any development of new fluorine compounds based on three or more carbon hydrocarbons would be much more complicated and costly, so we would expect costs to greatly exceed the $100 million Du Pont has expended to date on development of two-carbon alternatives.

As to whether a 5% ODP is too high, we believe the answer is no. HCFCs, with minimal potential to deplete ozone and with performance approaching that of CFCs, provides the best alternative for minimizing atmospheric chlorine and protecting the ozone layer. Acceptance and use of these HCFC alternatives will lead to the most rapid conversion away from CFCs and the broadest global acceptance of that conversion. Without these alternatives, users worldwide may extend their use of CFCs until lower-ozone-depletion alternatives can be developed. The amount of chlorine that would be added to the stratosphere from CFC use during the additional 15-year development period would be unacceptable.

15. a. *How much of an investment must the CFC industry make in substitutes?*

Du Pont estimates its investment will exceed $1.5 billion to replace existing domestic capacity for CFCs with equal capacity for HCFCs and HFCs. User investment will also be significant, but we have no estimate. We do know that in the U.S., the $600 million in CFCs sold each year generate $28 billion dollars of goods and services, suggesting that these will be some multiple cost factor in downstream industries.

b. *Might developing countries enter the market for the old CFCs if we abandon them unilaterally?*

Since CFCs are so fundamental to economic development (food chain, construction, etc.), developing countries will provide for internal needs by building their own facilities -- if developed countries fail to provide the needed products. It was in recognition of the basic needs of developing countries and the international community's desire not to encourage the construction of new CFC-producing facilities that the Montreal Protocol allowed developed countries to produce at levels up to 10% above their 1986 production base so that developing countries' needs could be met for a ten-year period.

The developing countries are becoming more concerned about their ability to adhere to the Protocol if the HCFCs, the very alternatives that they would convert to, are regulated.

A U.S. producer has sold CFC technology into India and Taiwan. The facility in India is in operation and the plant in Taiwan is under construction. While most of the developed countries have decided not to sell CFC technology, there are developing countries that possess and could sell the technology.

16. *Will users of CFCs be able to "drop substitutes into" production of goods?*

The HCFC and HFC family of substitutes are not drop-in replacements; that is, for all but possibly a few applications they will not be functional in equipment or applications designed for CFCs without some equipment modification. Du Pont has recently announced several products which are mixtures of compounds from the fluorocarbon family and may prove to be near drop-in replacements. That is, they may be functional in existing equipment or processes with minimal modifications. However, about 2 years of testing will be needed to determine what modification will be required in each application. We expect minimal changes will be needed in appliances, such as refrigerators. For automobiles, we believe more significant modifications will be required, but there is a possibility that auto manufacturers will be able to produce a car within two years that can operate on either CFC-12 or one of the new mixtures. We do not believe this will be possible for CFC-134a, so the mixtures may offer the possibility of a faster phase-out.

17. *Should we accelerate the schedule set forth in the Montreal Protocol? Should we take unilateral action?*

The U.S. should fully support the Montreal Protocol and push hard for 100% global compliance of an eventual total CFC phase-out. Unilateral action by large consuming nations could seriously concern developing countries that

will be dependent upon the permitted "ten-year exception" and developed world source for CFCs. The primary issues that the world must address are (1) how fast can alternatives be safely introduced in large commercial quantities, (2) how soon can the massive and diverse industry users convert their new product lines totally away from CFCs, and (3) how successful will the U.S. and other nations be in servicing the needs of existing CFC-using equipment. This critical last issue is dependent upon (1) aging rate and life of existing CFC-using capital equipment and the rate it can be retired from service, (2) the suitability of alternates that can be retrofitted into existing equipment, and (3) the possible use of recovered and recycled CFCs to fill a portion of the service equipment.

We believe Du Pont has a leading position in the effort to introduce alternates to CFCs. Our very ambitious schedule assumes that we can introduce acceptable materials beginning in late 1990 and have a full range of commercial products introduced in a three- to five-year time frame. This goal is dependent upon successful process development scale-up, market acceptance of the products, acceptable toxicology and approval by EPA for wide-scale commercial use, and a continued favorable business climate to attract the tremendous capital investment.

18. ***What incentives should the federal government provide to make CFC substitutes affordable and useful?***

The government and regulatory agencies can be instrumental in facilitating the transition by providing specific dates for the phasedown and phaseout of CFCs with achievable schedules for accomplishing both steps.

Bills are being proposed that call for the regulation of HCFCs. These compounds have 2 - 10% the ozone depletion of CFCs, are the result of +15 years of research to define suitable alternatives, and represent a large part of the family of substitutes that are being developed to allow for transition away from CFC use. Uncertainty over the future of these compounds can slow the transition. Producers will be reluctant to invest in products that might be regulated. Likewise, user industries are reluctant to invest in conversion to products that have an uncertain future in situations where they must assure their customer a 20 - 30 year product availability to service equipment. If HCFCs are regulated, the worldwide phaseout of CFCs could be delayed or stopped, rather than accelerated. If our goal is long-term protection of the environment, we cannot let this happen.

The industry (producers/users) is facing a considerable challenge over the next 10 years to transition away from

CFC use. This transition will require considerable resources at all stages of the value chain to make design and equipment changes to accommodate substitute products. Government actions that extract these needed financial resources via tax, fee, auctions from this industry will slow conversion to alternatives and negatively impact the environmental issue that the Montreal Protocol is attempting to solve.

It is interesting to note that the U.S. appears to be discouraging the transition away from CFCs while, as an example, the Japanese government is offering incentives (tax, investment credit, etc.) to encourage the use of alternatives.

SENATOR KERRY'S QUESTIONS

19. *In your prepared testimony, you listed the following barriers to replacing CFCs:*

a. *Incomplete basic data for design of world scale plants capable of high yields at favorable investment and operating costs.*

Development of basic data for a viable commercial plant is time-consuming (once laboratory leads are obtained) for several reasons. First, most processes require catalysts to direct the chemical reaction to the desired products at an efficient rate. Catalyst "life" is a major determinant of the ultimate commercial success. Only extended, "real time" runs in equipment simulating actual commercial conditions can define how long a catalyst will operate effectively or if/how it can be regenerated after deactivation, a periodic occurrence with almost all catalysts.

A second critical factor relates to materials of construction. Because fluorocarbon processes employ hydrogen fluoride and hydrogen chloride, very corrosive conditions exist in operating equipment. Again, extended runs are required to define the limits of potential materials to be used in the plant. Often minor process impurities (e.g., water) will build up in the acids over time and create corrosive conditions which cannot be simulated in the lab. It is important to define these conditions before commercial start-up to minimize potential for hazardous emissions.

Another time consuming factor is determination of the fate of minor by-products which could build up in the process. Since often these compounds exist in very

low concentrations, it is difficult to analyze for them, isolate them, and develop techniques to control unless extended reactor runs are employed.

A final area of basic data collection is determination of product quality acceptable to customer end-uses. This is often an iterative process in which product of a particular composition is prepared and tested in customer test equipment. If problems occur in his equipment (often related to his materials of construction), further evaluation in both process and end-use is required.

b. *Lack of complete toxicity profiles for all of the alternative candidates.*

Du Pont is involved with other CFC producers in development of the toxicity profiles of the substitute chemicals. Consequently, we do not need assistance in developing this data. The major potential barrier is any unreasonable restriction to market development which might be imposed by EPA's Office of Toxic Substances until they are convinced that the compounds are not potential human carcinogens. Because of recent GAO recommendations that EPA implement significant New Use Rules (SNURS) to limit commercialization of the TSCA listed compounds, like HCFC-123 and HFC-134a, and that EPA use its TSCA authority to limit commercialization of non-TSCA listed compounds, like HCFC-141b, HCFC-124, and HFC-125, producers and users will be more reluctant to make early investments in commercial facilities. An early resolution of this issue is needed to speed development of these new substitutes.

c. *Incomplete or inconsistent thermodynamic and transport property information on all of the identified alternatives.*

Government funding of NIST activities establishing an alternatives data base and testing new energy-efficient products will help resolve this barrier.

d. *Signals at EPA and in the halls of Congress that some of the identified alternatives will have insufficient product lifetimes to justify the investment needed for us to produce them and for our customers to develop equipment to use them.*

e. *High capital needs and an uncertain business climate.*

The reply to Senator Hollings question listed as #8 speaks to issues 19d and 19e. We quote in part from that reply:

- o Classing HCFCs similar to CFCs or Halons would raise serious doubts for investors in the CFC-producing and using industries.
- o Inclusion in the Protocol and implied future production limits raises the specter of the market out-pacing capacity and an allocation of production rights, not just within a country but between countries.
- o Many environmental regulations have led to an ultimate ban on a product, a difficult climate for supporting huge capital investments.

f. *Threats in the U.S. of auctions or taxes that will divert needed revenue streams from the private sector to the government's general fund.*

Auctions, taxes or fees that extract $4 billion in five years from the CFC industry are a hidden tax on consumers that will hinder the effort by industry to rapidly introduce and utilize ozone protecting compounds and technologies, and will place the U.S. economy at a competitive disadvantage with Japan and the European community in the race to take the worldwide lead in these technologies.

CFCs in aerosols were phased out in the U.S. a decade ago and the remaining uses are critical to the economy and the quality of life in the United States. Rapid introduction of CFC substitutes are essential to the smooth transition to ozone protecting technologies with a minimum of economic disruption. More than 700,000 jobs and $28 billion in annual goods and services in the United States rely on the current $600 million in CFC compounds. Critical industries include refrigeration, air conditioning, electronics, food processing, medical, national defense, transportation, and high energy efficient foam insulation.

The proposal to auction off the "rights" to produce the current CFC compounds could allow certain price insensitive CFC user industries to delay utilization of ozone protecting compounds by allowing those industries to assure certain supply of the current CFCs, i.e., automotive air conditioning uses 1/6 of CFC output.

A large, sudden CFC price increase 2-5 years before significant commercial quantities of alternates are available could be extremely counterproductive. It could force industries, such as blowing agents and cleaning agents to move to less efficient or environmentally less desirable alternates, i.e., more toxic, water polluting, flammability or energy shortcomings.

The proposed unilateral U.S. auction is non-global and does not represent a true "market clearing" exercise as proposed by theoretical economists. Furthermore, it puts U.S. companies at significant competitive disadvantage opposite global competitors who will use their domestic revenues to support their alternatives effort.

Du Pont agrees that a large tax on CFCs will force industry to conserve, recycle and stop using CFCs wherever practical; minimizing CFC consumption. However, without sufficient alternatives to switch too, several businesses or industries will be forced by high prices to exit the market with associated dislocation of thousands of jobs.

The CFC business has struggled with low margins and earnings since production was scaled back 50% in North America when CFC aerosols were banned. The business cannot absorb any government imposed charges and sustain the aggressive research and investment needed for $2-3 billion in 10 or more facilities costing around $200 million each over the next decade.

g. ***The need to complete development, evaluation and design of retrofit technologies so the current equipment which relies on CFCs (U.S. investment alone exceeds $135 billion) will serve for its useful life.***

The development and implementation of retrofit technologies for the $135 billion worth of CFC-using capital using equipment is critical to achieving a rapid and total CFC phase-out. For example, there are over 80,000 large industrial chillers in the U.S. (used for manufacturing process needs, energy recovery, air conditioning, etc.) and the U.S. capacity to manufacture these machines, which can cost hundreds of thousands of dollars each, is less than 4000 per year. Not only would replacement of all this capital equipment be a tremendous capital drain, but the manufacturing and installation capacity does not exist to accomplish such a task in a short time frame. In many cases, lack of operable

air conditioning equipment would be a serious health problem to senior citizens or health facility patients.

h. *What is the status and our time table for overcoming each of these barriers, and how can the government, EPA, DOE, and NIST help in speeding up the process and overcoming these barriers?*

We have a "network plan" in place to deal with full development and commercialization of effective CFC replacements. The plan has multiple paths where uncertainties exist and is upgraded monthly as new data is generated by our development effort and market feedback. Our near 200 year history of inventing, perfecting, and introducing new products and processes is being brought to bear on this problem.

The primary concern in successful development of alternatives for CFCs are external forces that depend on government to control or influence; i.e.

- o Toxicology data for permitting full commercial production of alternates must be reviewed in a sound scientific basis and approved in a timely fashion so that the marketplace is able to plan the development and commercialization of new products.
- o Realistic regulatory deadlines to stop the manufacture of new equipment that depends on CFCs.
- o A definitive position on the acceptability or unacceptability of proposed alternative products and technologies (HCFCs) so industry can focus their resources on activities that are viewed as true long-term solutions.
- o Clarifications of the government intent on extracting financial resources from the CFC-producing and using industry so that industry can determine if investments for alternates are going to be economically possible in the U.S. market.

20. *DOE currently is in the process of promulgating new regulations for improving the energy efficiency of home appliances. At the same time, refrigerator manufacturers are concerned that they will soon be required to replace CFC refrigerants. I understand that these substitutes are not as energy efficient. This situation obviously has the potential to have a serious negative impact on the industry.*

a. Can you offer any suggestions for improving the regulatory process to reduce such conflicts?

b. How can the industry become more constructively involved in the regulatory process?

We recommend the use of the regulatory negotiation process to bring all of the interest groups, including government regulators and environmental groups, together in an attempt to first understand what is possible, and then reach agreement on a plan to get there. While the process may not achieve consensus, it is the only forum available to get all the interest groups together to negotiate an agreement.

21. *It is my understanding that CFC 113 is currently used to clean computer chips. What types of alternatives are being developed in this area? How quickly can new methods be developed and implemented? What impact will this have on the computer industry?*

CFCs are used extensively in the electronics industry, primarily as cleaning agents for removing flux from printed wiring assemblies (circuit boards). The quantity of CFCs used in the manufacture and cleaning of computer chips is small compared to cleaning of circuit boards, but the use is critical to manufacture high quality product. Du Pont research to date has identified one potential long-term candidate, a ternary HCFC-141b/123/methanol mixture, which may be useful as a substitute in defluxing boards and in other computer related cleaning applications. In addition, Du Pont has identified a non-halogenated biodegradeable hydrocarbon-based cleaning agent which may be useful only in defluxing boards. The non-halogenated product should be commercially available by the end of 1989 with the ternary mixture to follow in several years.

The most significant barriers to quick widespread use of these products will be the time needed for customer evaluation and the need for new equipment. At this time, there are no commercially available machines in which either product can be effectively utilized. While this equipment may be developed by year end, equipment manufacturers can produce new equipment at a rate of about 4000 units per year, and since there are in excess of 40,000 units being used, it will take years for the industry to phase-in any totally new systems. The same barrier applies to water cleaning systems, which some users may consider.

The computer industry could be seriously impacted if acceptable cleaning options are not available. The industry is moving to more powerful machines requiring more

densely packed, close mounted components with closer, narrower lines on the board. Without effective cleaning systems, the move to these powerful machines could be impeded. If these effective cleaning systems are more readily available outside the U.S., then there could be a move to offshore production and U.S. companies could be placed at a serious competitive disadvantage.

SENATOR KASTEN'S QUESTION

22. a. *Shouldn't we stress the need for an international effort if we're going to control the technology of production of CFCs and their use in end products?*

Du Pont and the Alliance for Responsible CFC Policy, the U.S. producer/user industry that represents 500 U.S. companies, have consistently advocated a global approach. We believe that U.S. unilateral action in the mid-1970s aerosol ban led to complacency in the rest of the world on the need to further develop stratospheric ozone knowledge. The Montreal Protocol is a historic document on global cooperation and should be strengthened as called for by the scientific reassessment process currently underway.

b. *Don't we have to guard against adopting a U.S. CFC ban, which could just result in having foreign countries continue to use ozone depleting products and the U.S. importing the end products?*

We are seriously concerned that precipitous action by the U.S. that is not based on technological or scientific realities would signal to the undeveloped world that they can't rely on the U.S. for meeting their basic domestic needs that currently can only be provided by using CFCs. They will most likely add their own CFC capacity if they fear their needs will not be met, and once these facilities are built, they will defeat the phase-out effort of the developed nations and stratospheric ozone will be subjected to increasing quantities of chlorine and possible depletion.

c. *This would not only continue the environmental harm, but cause unilateral economic harm to the U.S. Could you comment on this please?*

The U.S. can have the maximum economic advantage in the CFC alternative business if U.S. industry is supported in the global race to final alternatives. There is an enormous transition that must be made in a wide range of industries. The companies and nations that come up with cost effective, environmentally sound solutions are going to position themselves for decades to come in the

many critical global markets for goods and services now satisfied with CFCs.

SENATOR MC CAIN'S QUESTIONS

23. *How does the cost of possible substitute compounds compare with those currently used?*

See question 11a and answer. In addition, I offer the following observations.

CFC-11 and 12 are single carbon molecules made from carbon tetrachloride. A single process can manufacture the two materials, and they are easily separated due to their wide range in boiling points. CFC-113 is made from perchloroethylene and is a two-carbon molecule. Processing is still via a single reaction step, but potential by-products or co-products are greatly increased because of the many possible structure arrangements for the chlorine and fluorine on the two carbons making CFC-113 more expensive than 11/12. CFC-114 and 115 are even more costly to make because of the need to be selective in controlling the chemistry and due to much more difficult purification technology to get the desired pure products.

CFC-114 and 115 have increasingly higher manufacturing costs due to process complexity and scale of manufacture; large plants generally provide lower unit cost of manufacture for a specific chemical.

CFC-134a is going to require at least two manufacturing steps to produce it, and there are many possible starting materials, co-products, and by-products possible. This complexity is illustrated by the attached chemistry structure chart (Attachment 3). Thus, it will be more costly than CFC-114 and CFC-115.

All alternates will be more expensive because of higher investment and because alternatives use more of the expensive hydrofluoric acid ingredient to displace chlorine from the chlorocarbon starting materials.

24. *Concerns have been raised that implementation of the Montreal Protocol will result in windfall profits for producers and that the financial gain might discourage companies from marketing substitutes as soon as possible. What are your views on this?*

Claims by the EPA of $7 billion in windfall profits to U.S. CFC producers between now and the year 2000 were based on a study conducted last year that included assumptions not appropriate then, much less now. EPA estimates of revenue transfers to producers were based on unrealistic price increases; for example, EPA projected the price in 1989 to

be $3.04 above 1988 prices. In reality, year-to-date price is only $0.13/lb. higher than 1988. The study also equated revenue increases with profits and completely ignored higher costs that have, and will continue to fall on producers (see question 4). It was also assumed that users would not implement low cost solutions or alternatives to CFCs. This, of course, has not been the case. Since our introduction of Formacel® as an alternative blowing agent to CFC-12 for polystyrene packaging, essentially all of that market has converted away from CFC-12. Other examples include a major consumer announcing intentions to convert to alternative HCFC-142b for polystyrene insulation, hydrocarbon-based cleaning agents finding use in certain defluxing operations, and reclaim, recycle and recovery being implemented in the refrigerant and cleaning agent markets. Of importance to note is not only has the industry been implementing options as they become available, but has done so in advance of regulatory actions. The EPA study also assumed that large revenues would be generated from the sale of large quantities of CFCs into the market at the turn of the century. Not only has Du Pont announced its intention to phaseout production by the turn of the century, but there is a growing consensus in the worldwide community to phase-out versus phase-down leaving it very unlikely that CFCs will be sold into the U.S. market at any appreciable level during the late 1990's.

We believe that the responsible action taken by Du Pont and other CFC producers to develop substitute products for CFCs is a direct contradiction to the claims by the EPA and OMB that producers will delay introduction of alternative products so as to realize financial gains from continued CFC production. We, along with our customers, are anxious to make the transition to alternative products.

Allied and Atochem joined R&D efforts to combine resources and speed their development of alternatives as did Kali and ISC. We estimate from published data that the CFC producers worldwide will spend $90 - 100 million on R&D in 1989, twice the level of $55 - 60 million in 1988, and five times the $16 - 20 million spent in 1987. Du Pont represented more than half of the expenditure, not including the authorization in 1988 of a $25 million plus HFC-134a interim commercial plant at Corpus Christi, Texas. Additionally, during the past 18 months, Du Pont has brought seven different pilot plant facilities into operation to make alternative products to meet the needs of toxicity testing and customer evaluation, has introduced, and is selling, three commercial alternative products (Formacel®, Freon® SMT, Freon® MCA) and announced three other products/blends under development. Industry is acting responsibly and aggressively to develop and commercialize safe substitutes for CFCs. Government efforts to capture alleged windfall profits will be as counterproductive as the now repealed windfall profits tax on the oil industry. In this case, they will disrupt industry efforts to manage an orderly transition to substitutes, and will delay commercialization.

ATTACHMENT #1

WINDOW AIR-CONDITIONER CONDENSER TEMPERATURE OF 120°F

CONDENSER PRESSURES WOULD BE:

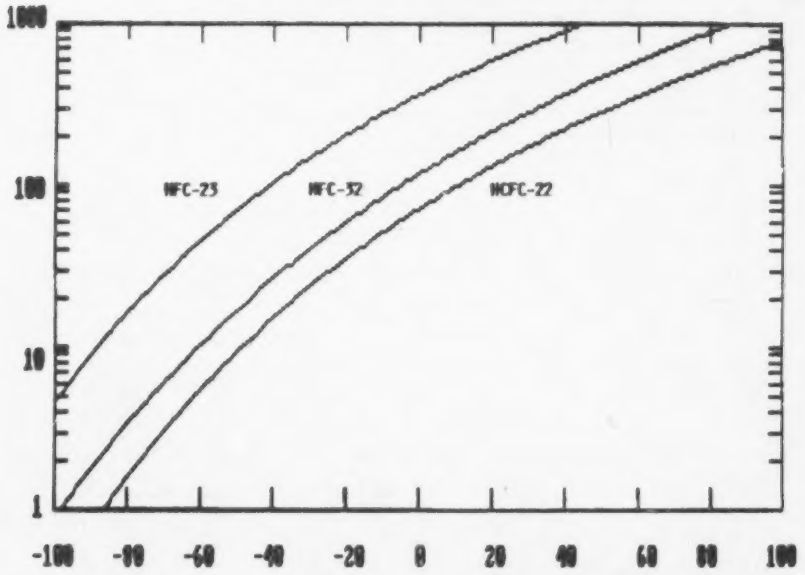
HCFC-22	275 PSIA
HFC-32	450 PSIA
HFC-23	> 800 PSIA

ATMOSPHERIC PRESSURE BOILING POINTS

HCFC-22	- 41°C
HFC-32	- 52°C
HFC-23	- 82°C

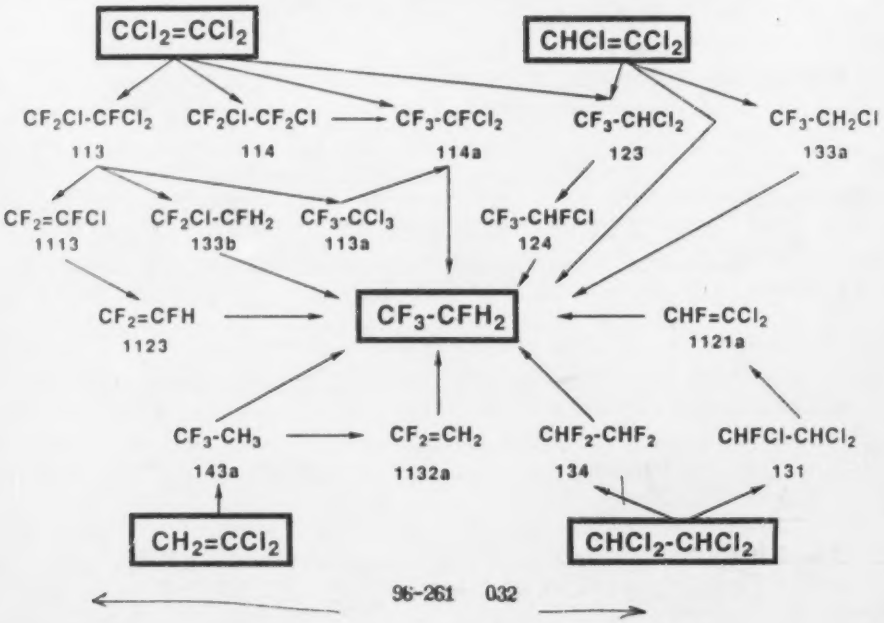
ATTACH1.CHT
4/19/89

PRESSURE (psia) vs. TEMPERATURE (C)



ATTACHMENT #2

POTENTIAL ROUTES TO FC-134a



ATTACHMENT #3

Senator GORE. Thank you very much.

We will hold off on questions until the entire panel has completed the prepared statements.

Dr. Robert Traflet, President, Fluorine Products, Allied-Signal, Incorporated.

STATEMENT OF ROBERT TRAFLET, PRESIDENT, FLUORINE PRODUCTS, ALLIED-SIGNAL, INC., MORRISTOWN, NJ

Mr. TRAFLET. Thank you, Senator. You gave me a little more education than I have. I am a chemical engineer with an MBA, but I am not a doctor.

Senator GORE. Oh, sorry about that. We will promote you, Bob.

Mr. TRAFLET. Okay, thank you.

I am President of Allied-Signal's fluorine products division. On behalf of Allied-Signal, I appreciate the opportunity to share our views on the issue of stratospheric ozone depletion with your Committee.

Chlorofluorocarbons are a part of the fluorine products division of Allied-Signal. We manufacture and market a broad range of these materials, including CFC 11, 12, 113 and 114, at domestic manufacturing facilities located in Baton Rouge, Louisiana; Danville, Illinois; and El Segundo, California.

We also manufacture refrigerant 22. We also manufacture solvent cleaning systems, equipment systems through our Baron-Blakeslee unit. CFC's have many valuable properties, such as stability, low toxicity and nonflammability. They are used by many essential American industries providing our society with comfort and health controls, energy conservation and the ability to clean micro components of electronics.

The letter of invitation to this hearing asked us to comment on, among other things, our views of the recently released preliminary findings of the Arctic Stratospheric Ozone Research Team.

Obviously we have not had time to give this information the review it deserves, but we have taken this problem seriously for a long time. This new information reinforces our earlier decision to move as rapidly as possible to develop safe substitutes for those CFC's regulated by the Montreal Protocol.

Last March the Ozone Trends Analysis Report was published which indicated that total ozone amounts have decreased at northern mid-latitudes between 1969 and 1986. The report also indicated that in combination with the unique meteorology of the Antarctic, chlorine from manmade compounds plays a major role in the seasonal losses of ozone.

We have reviewed this report thoroughly and came to the conclusion that fully halogenated CFC's, those products regulated by the Montreal Protocol, should be phased out on a global basis to the maximum extent feasible. We called at that time, for the Protocol to be reopened for this purpose.

In fact, UNEP has initiated the international process for the reassessment of the science and the technology associated with the Montreal Protocol and by April 1990, will consider and adopt amendments to the Protocol.

I would like to review for you some of the steps that Allied-Signal has taken to bring the new CFC substitute products to market. In 1988, to accelerate the pace of substitute development, we formed a joint process development partnership with ATOCHEM, Europe's largest fluorocarbon. We have continued to increase our staff of scientists dedicated to fluorocarbon development.

Our most recent staff expansion, announced in July of 1988, increased the size of the team by 75 percent and we are still recruiting engineers for our CFC substitute program. We have already seen results from these resource commitments. Allied-Signal received a patent on a promising family of lubricants. New lubricants are needed in air conditioners and refrigeration compressors in order for the new substitutes to work.

By this summer, we will start operation of our second pilot plant producing substitute CFC's at our fluorocarbon research center in Buffalo, New York. The two primary purposes of a pilot plant are to develop a manufacturing process and to provide larger quantities of the new products to customers for evaluation and process development.

We have already provided numerous samples of the promising substitute to all the major end use segments. These include 134-A, 123, 124, 141-B, and a number of blends. Also our Baron-Blakeslee unit is introducing a new line of equipment designed to limit the emission of CFC 113 to the atmosphere during cleaning operations.

In addition, it is working on equipment to utilize the new substitutes. We have also established centers near Silicon Valley, California and Chicago, Illinois to take back spent or contaminated CFC 113 solvent for recyclying and reuse.

We project that Allied-Signal has spent $250 million during the next 10 to 12 years to bring a family of stratospherically safe fluorocarbons to commercial reality. In addition to all of this promising research into new products and ways to promote conservation, there is a key testing program that is underway that I want to bring to your attention.

One of our primary goals is to make certain that substitutes are safe. In order to do this, Allied-Signal has joined with several other fluorocarbon producers to undertake programs for alternative fluorocarbon toxicity testing or PAFT I and II.

These organizations were formed to expedite the toxological testing of three of the key substitute products—123, 134-A and 141-B. We want to make certain that we are not exchanging one set of problems for another.

I have only highlighted for you and the Committee some of the steps we are taking at Allied-Signal. The real story is much larger.

This larger story involves many groups of people. It involves a family who bought a refrigerator containing a controlled product, but still expects it to last 20 years. It involves the manufacturer of that unit, who is concerned about servicing it over time. But also is developing new systems for developing the substitute products, for using the substitute products.

It involves the American electronics industry, which is fighting to maintain its competitive position, but which faces the need to change the way it cleans its micro-circuitry.

It involves hospitals which use the controlled products and systems to sterilize medical and surgical equipment. It involves our building industry which utilizes CFC's to make insulation that brings energy efficiency to our homes.

At Allied-Signal we feel that we are in a partnership with these groups, from the housewives to the hospitals. This partnership between producer and user is critical because without it, we run the risk that substitutes will be available, but those who have to use it will not be ready.

For example, let us look at the situation in automobile air conditioning. CFC 12, a controlled product, is used in combination with a variety of commercially available lubricating oils to provide both cooling and lubrication for today's auto air conditioner. However, the new substitute for CFC 12 is incompatible with these oils and new ones are required.

I mentioned after several years of intensive research Allied has developed a new class of lubricants which show promise for auto air and refrigeration applications. We are working very closely with automobile and refrigeration manufacturers to determine the best way to use the lubricant/refrigeration combination.

The auto companies will have to modify system hardware and conduct automobile field tests of the new air conditioning systems. Thus, it takes a combined effort of the producer and the user to develop a new refrigeration system.

In rigid urethane insulation, Allied again works closely with users. We have evaluated two potential substitutes for CFC 11, the controlled product and provided a great deal of information on the best way to employ these substitutes. However, no satisfactory insulation system can be developed unless and until end users complete the evaluation cycle already underway.

This effort includes not only measurements of foam energy efficiency, but actual full scale room tests for flammability and insulation value. Indeed, it is the fabricated foam incorporating the chemical substitute, rather than just a chemical substitute, which must be demonstrated to comply with the numerous regulatory codes.

Our goal is not just to have substitutes available as soon as possible. Equally important is the availability of systems to utilize these new molecules. Mr. Chairman, this takes time, but we are confident that the partnership that I have just described will make it possible.

Assuming we find acceptable substitutes and develop the systems to utilize them, we are then faced with a transition period.

This transition will not take place overnight. The fact is that billions of dollars of equipment designed to use controlled CFC's will still be in use in the 1990's. Mr. Chairman, it is not business as usual at Allied. We are on a very tight time schedule. If everything works right, we hope to have acceptable substitutes available in three to four years.

And I want to assure you and the Committee, however, that we will not cut corners where the safety of our workers and the safety of the public are concerned. We will not commercialize a product just to be the first one to market. CFC's are used in many different

ways and we will understand the safety of these products in all potential uses and applications before we recommend their usage.

For instance, as I mentioned, Allied and other producers are working on substitutes to be used in the manufacture of rigid foams. We are in a hurry to do this, but we will not be rushed to the point where we put a product in the walls of homes that would expose homeowners to health risks or the risk of fire.

As I said earlier in my testimony, Allied-Signal supports the reopening of the Protocol to consider further global reductions. These reductions, however, should not occur at the front end of the process. Producers, users and consumers need to have some transition period. Our substitutes must be safe. The systems for using them must be developed. And servicing of existing equipment must be maintained for a period of time.

At one point, during the Protocol negotiations, the U.S. position was for deeper global reduction in the production and use of the controlled CFC's by the turn of the century or shortly thereafter.

In our opinion, this position is still valid and we recommend that when the Protocol is reopened, as it must be, that the U.S. once again take the lead in urging further reductions on the whole world.

This country only produces about 30 percent of the world's production of CFC's with 70 percent coming from the rest of the world.

Mr. Chairman, I also urge that we continue to operate within the framework of the Montreal Protocol. Unilateral action could leave idle billions of dollars worth of equipment, raise the cost of CFC-containing goods to the consumer and make certain American businesses are no longer competitive in the world market place.

If we show our leadership by getting the rest of the world to agree to further reductions, than currently mandated by the Protocol, we would be doing significantly more to protect the stratospheric ozone, than if we go it alone.

In summary, Mr. Chairman, we are in a very competitive race on a global playing field that has been leveled by the ratification of the Montreal Protocol. If all the toxicological data turns out to be what we hope it does and if we continue the progress we have made on process technology and systems development, we will have substitutes in the market place by the time table of the next reduction mandated by the Protocol.

We are committed to meeting the challenge and we look forward to working with you and the others in the Congress to help make this commitment a reality.

[The following information was subsequently received for the record:]

QUESTIONS OF THE COMMITTEE MEMBERS

Q. FROM SENATOR GORE

(1) Why hasn't Allied released all thermophysical data on substitutes it has investigated to user groups so they can evaluate the merits of various refigerants and mixtures on their own?

Response:

Amongst the companies engaged in chlorofluorocarbon substitute research, ALLIED-SIGNAL has been at the forefront in developing and quickly disseminating information on physical and thermodynamic properties of the entire range of substitutes to user groups directly involved in the redesign and conversion of CFC-containing systems and equipment. We have a dedicated group of scientists whose prime function is to estimate and then to determine, with great precision and accuracy, the thermophysical properties of chlorofluorocarbon substitutes. Our business has committed substantial cost, resources and effort to generate this information, and the end products have been internationally recognized as some of the highest quality thermophysical data on this class of chemicals. This information has been and will continue to be promptly shared with the widest range of end-users in the refrigeration and air-conditioning industries. Indeed, it is in ALLIED SIGNAL's best interest to work closely with end-users so that we can help to facilitate the timely switch from ozone depleting chlorofluorocarbons to environmentally acceptable substitutes. ALLIED SIGNAL scientists gave the first public, technical papers on the physical and thermodynamic properties of HFC-134a and will provide similar information on HCFC-124 at a forthcoming meeting of the AMERICAN SOCIETY OF HEATING, REFRIGERATION AND AIR CONDITIONING ENGINEERS. ALLIED SIGNAL expects to continue its policy of providing timely and accurate thermophysical data on the entire range of substitutes to enable end-users to evaluate and apply these products well in advance of their commercial availability.

Q. FROM SENATOR HOLLINGS

(2a) Any comprehensive strategy to cut CFC emissions will require developing CFC alternatives, developing new technology, and instituting CFC recycling programs.

Which steps do you think will yield the largest reduction in emissions most quickly and for the least effort?

Response:

We believe that there are a number specific CFC recycling programs which could be instituted or encouraged to significantly reduce CFC emissions in the near term. For example, CFC-113 reclaim and recycling centers are already in place at various locations throughout the U.S. Presently, modest amounts of "spent" or used CFC-113 are returned by end-users to these centers for reconstitution. If this practice is encouraged and low emission equipment and modifications such as carbon absorbtion are utilized, a greater proportion of the 150M lb. of CFC-113 used annually could be conserved.

At the present time, the recycle of CFC-12 from automotive air conditioning systems is being actively supported by the automotive industry. Quality specifications for recycle CFC-12 will soon be set and multiple locations equipped to recover used CFC-12 from autos. It has been estimated that once such a system is in full operation, some 30 million pounds of CFC-12 could be recovered for recycle.

Possibly the largest intermediate term reduction in CFC emissions could take place in the rigid urethane industry as end-users switch from CFC-11 as a blowing agent to a

substitute such as HCFC-141b. Urethane producers have an ongoing, active program to evaluate and qualify substitutes and they would be in a position to utilize such a product without major modifications of their operations. Similarly, HCFC 141b azeotropes may provide opportunities to substitute for CFC 113 in precision cleaning and defluxing after equipment modifications. If HCFC-141b proves acceptable toxicologically and continues to show acceptable performance, a major reduction in the CFC-11 and CFC113 agent use is possible in the 1992-1993 time frame as HCFC-141b become available commercially.

Q. FROM SENATOR HOLLINGS

(2b) Are their federal laws and regulations that are making cutting CFC emissions more difficult?

Response:

There are two areas where federal regulations have slowed certain facets of CFC emission reduction.

There is a significant use of CFC-113 based solvents, perhaps as much as 25%, by military contractors which must conform to various military specifications requiring the use of these materials. Changes to these types of military specifications have traditionally been very slow. To encourage the use of non-CFC solvents and other cleaning methods in these areas, mechanisms to more quickly qualify under the military specifications are desirable. This is a recognized barrier and the EPA has formed an ad hoc committee to rectify the situation. We are serving on that committee.

The second area where federal regulations have been a barrier is in the delays experienced in permitting of waste solvent collection depots. These are staging areas where waste CFC solvents are collected prior to being shipped to recycling centers. The lack of these sites complicates the logistics of solvent recycling especially for the small CFC solvent users. We think that a speed up of such permitting poses no environmental risk.

Q. FROM SENATOR HOLLINGS

(3a) The federal government spends millions of dollars a year funding R&D on replacing CFCs. One program at the National Institute of Standards and Technology which evaluates CFC alternatives was recently expanded.

Have such programs been useful?

Response:

The usefulness of government funded R&D varies tremendously. In virtually every case, the utility could be improved via better communication with end-users and suppliers such as ALLIED-SIGNAL. The NIST program to generate precise thermodynamic and transport data on R-123 is of great value, although we feel that the proposed form of the thermodynamic equation is cumbersome and could have been improved by increased dialogue with industry. We continue to maintain an open door policy with NIST and other government R&D agencies to provide expert advice and consulting to help direct their technical efforts, as recently exemplified by our hosting the EPA AIR AND ENERGY ENGINEERING RESEARCH LAB of Research Triangle Park, N.C. at ALLIED-SIGNAL's BUFFALO RESEARCH LABORATORY on February 21, 1989.

(3b) In your opinion, which of these programs should the Congress consider expanding?

The programs which are appropriate for increased government funding would include thermophysical property measurements for more alternates and generic material compatibility evaluations of common materials of construction and realistic replacements.

Q. FROM SENATOR HOLLINGS

(4) Dr. Watson mentioned that the concentration of carbon tetrachloride in the atmosphere is increasing more than 1% per year. While carbon tetrachloride is not a CFC it does cause ozone depletion, yet scientists have not been able to identify the sources responsible for this increase.

If you had to guess, who would you blame for the increasing amount of carbon tetrachloride in our atmosphere?

How much carbon tetrachloride is produced in the United States each year?

Response:

ALLIED-SIGNAL does not manufacture carbon tetrachloride. I'm certain that others more familiar with the manufacturing and uses of carbon tetrachloride are much more capable of answering this question than I am.

Q. FROM SENATOR HOLLINGS

(5a) The production processes for CFC alternatives are much more complicated than the simple processes used to make most CFCs.

How much more expensive will CFC alternatives be?

Response:

It is impossible for us to estimate the cost of the substitutes at this time. We have process technology research that is ongoing and pilot plant assessments yet to be made. Without question, however, the cost of the substitutes will be greater than the current cost of the controlled product.

(5b) Will production of CFC alternatives lead to dangerous by-products which will be difficult to dispose of?

Response:

The production processes for several of the CFC substitutes under study may lead to very small amounts of one or two by-products with potential toxicity greater than many chemical products used commercially. There are numerous chemical and physical methods to destroy such by-products, and the most effective method will be incorporated into the production process so that both production and consumption of substitutes will be entirely safe. In addition, small amounts of CFCs may be formed as by-products in the synthesis of some substitutes. Here again, both physical and chemical methods are available to destroy the minute quantities of substitutes which would not add to emission of any CFCs to the atmosphere. We are presently studying and evaluating several alternative production processes with the direct objective of minimizing or eliminating all by-product formation and in so doing, develop the safest most cost effective process possible. It is very likely that we will be able to hold the formation of the by-products to a minute percentage of the product, but less likely that they can be entirely eliminated since the high temperature chemical reactions required to form substitutes, such as HFC-134a, are almost always accompanied by undesired parallel reactions leading to by-products. These by-products will be disposed in the most responsible manner possible.

Q. FROM SENATOR HOLLINGS

While carbon dioxide is the largest contributor to greenhouse warming, CFCs are responsible for about a fifth of the problem. Many of the replacements for CFCs are also greenhouse gases.

(6a) Are they better or worse than CFCs in this respect?

Response:

The atmospheric lifetime of CFCs range from about 70 years to 600 years, whereas the replacement candidate's lifetimes vary from approximately 2 to 35 years. By virtue of their much shorter atmospheric lifetimes, the replacements will contribute substantially less to "greenhouse warming" at equivalent release rates to the atmosphere. Therefore, they are better than CFCs in this respect. In fact, the substitute for CFC-12 has only about one-tenth of its greenhouse potential.

(6b) Would you be hesitant to go into production of a CFC replacement that was a worse greenhouse gas than the CFCs they replace?

Response:

Uncertainty in the business world is part of being in business, in fact we expect it. Presently, ALLIED-SIGNAL is looking at an investment of $250 million to commercialize substitutes for the CFCs controlled by the Montreal Protocol. The bulk of this expenditure will occur when we commit to building new plants or re-engineering our existing plant system to produce the substitutes.

Our management has been very supportive of our commercializing efforts and, without prejudging their decisions, I am confident of their continued support.

Lately, however, I have become more cautious in my predictions. Your question about the greenhouse concerns of substitutes is a case in point. First, we don't fully understand the indirect greenhouse implications of the substitutes. Secondly, however, your question goes to the heart of what I consider to be the key issue facing the

substitutes. Are they going to be regulated and if so, how and when?

It's my responsibility to make certain that management is fully informed about all the implication of a major decision such as the one we face with commercializing the substitutes. I would be less than candid if I told you that I feel as strongly about the direction of commercialization as I did six months or a year ago. All of the discussion about regulating the substitutes and using CFCs as a revenue measure is making us look long and hard at the next big step which for us at ALLIED-SIGNAL is very close.

Q. FROM SENATOR PRESSLER

(7) Are CFC substitutes safe? Some substitutes are only 5% as destructive as the current chemicals. Is 5% too high? Can you do better, and if so, at what cost?

Response:

ALLIED-SIGNAL will not commercialize products that are not safe. As I stated in my testimony we have several testing projects underway within ALLIED-SIGNAL and we are members of a an international group of CFC producers conducting substitute testing.

In regard to the question of the safety of the substitutes, one brief comment. We are working to develop and commercialize substitutes for those products controlled by the Montreal Protocol. One of those not controlled by the Protocol is CFC 22 which has always been considered part of the solution to ozone depletion. Presently, resources are not available to search for substitutes for CFC-22 while we work on substitutes for the others. This is not a question of money, it's a question of what is possible in the short term. We would also be concerned that any proposed controls on CFC 22 would dampen efforts to rapidly switch over to it from CFC 11 and 12.

Q. FROM SENATOR PRESSLER

(8) How much of an investment must the CFC industry make in substitutes? Might developing countries enter the market for the old CFCs if we abandon them unilaterally?

Response:

I can only comment on the investment that we at ALLIED-SIGNAL envision will be required to commercialize the substitutes. As I said in my testimony, $250 million will be required for all the work necessary to begin bringing these products to the marketplace in the next decade. This figure includes research, pilot plants, toxicological testing, engineering and plant construction among other items.

Whether or not lesser developed countries begin to manufacture controlled CFCs is something that I can only answer as far as ALLIED-SIGNAL is concerned. We have a corporate policy that we will not license CFC technology to lesser developed countries. However, I'm concerned about this issue and believe that UNEP should monitor it carefully.

Q. FROM SENATOR PRESSLER

(9) Will users of CFCs be able to "drop substitutes into" production of goods?

Response:

Every producer is hoping to find drop-in substitutes for the products regulated by the Montreal Protocol. Just within the last few weeks we have developed a drop-in substitute for a blend of CFC-12 and ethylene oxide. This blend is used as a sterilant gas by hospitals and the health care industry to sterilize reusable surgical equipment and health care goods. The current market for the blend is 30 million lbs.

Our research is continuing into substitutes for all applications of the controlled products and although it looks less and less likely that drop in substitutes will be found for broad application, our research attempts are moving forward.

Q. FROM SENATOR PRESSLER

(10) Should we accelerate the schedule set forth in the Montreal Protocol? Should we take unilateral action?

Response:

Our policy is that we support the Montreal Protocol and believe it should be amended to further restrict the manufacture and use of CFCs. Last year's Ozone Trends Panel Report and the scientific assessment called for by the Protocol to be completed this summer should be the basis for this revision. We believe that only through continued international efforts can the problem of ozone depletion be dealt with effectively.

Q. FROM SENATOR PRESSLER

(11) What incentives should the federal government provide to make CFC substitutes affordable and useful?

Response:

At the present time, I believe the market is going to make the substitute products affordable and usable. One of the success stories of this search for substitutes is the fact that the implementation of Montreal Protocol has levelled the playing field around the world rather than just in one county. This will allow a real market place approach to work.

Q. FROM SENATOR KERRY

(12a) Incomplete basic data for design of world scale plants capable of high yields at favorable investment and operating costs.

Response:

ALLIED-SIGNAL is working at a vastly accelerated pace to simultaneously perfect processes for a full family of CFC substitutes, and at the same time, gain basic design data in part through the operation of pilot plants so that world scale plants can be built and operated safely as soon as possible. Last June, we announced a pilot plant for HCFC-141b. This will soon be followed by additional CFC substitute plant now under construction. We continue our laboratory process development in parallel with pilot plant construction and operation so that full plant design data can be obtained as early as possible. This vastly accelerated and high risk process development effort will lead to the construction of an HCFC-141b plant early in 1992. Additional substitute commercial facilities will follow in the 1993-1994 time period.

(12b) Lack of complete toxicity profiles for all of the alternative candidates.

Response:

ALLIED-SIGNAL is a member of the industrial groups which are sponsoring toxicity tests on many of the CFC substitutes and we are desirous of extending the toxicity testing to include additional potential CFC substitutes. It is our understanding that from the inception of testing, a complete toxicity evaluation requires five to six years. Since such toxicity testing has already commenced on HCFC-123, 141b, and HFC-134a, it is entirely conceivable that we may begin to learn of final toxicity results on one or more of these compounds by late

1992. ALLIED has consistently maintained a policy of non-interference with either the timing or direction of the toxicity tests. In this way, we feel that independent, reliable and reproducible results will be generated, and if the substitutes are proven non-toxic, the public at large may have sufficient confidence to use them.

(12c) Incomplete or inconsistent thermodynamic and transport property information on all of the identified alternatives.

Response:

As noted, in the response to question NO. 1, ALLIED develops and disseminates appropriate thermodynamic/thermophysical data on candidates early in the developmental/commercialization process. This is an expensive, time-consuming task which involves the commitment of significant resources. Such efforts must be justified by a reasonable anticipation of achieving product commercialization.

Those molecules which have little likelihood of commercialization, due to inherent safety risks, infeasibility of manufacturing process, or improbable commercial demand, are less likely to receive an equivalent level of effort to precisely characterize their properties. In such cases, estimation methods have been developed adequate to support early assessment. Some of these methods are in the public domain. Others may not be.

NIST has stated that they hope to develop a generic model suitable for characterizing molecules for which limited measured data is available. ALLIED supports this concept. It should still be understood, though, that more careful and precise characterization is still likely to be required on those molecules which eventually emerge as viable working fluids.

(12d) Incomplete development of equipment that can use the alternatives.

Response:

Refrigeration systems and individual system components are designed and optimized for specific refrigerants to achieve reliability and operating efficiency. Direct "drop-in" refrigerants are thus infeasible to varying degrees depending on the extent of divergence of the new candidate fluid to reference fluid.

Whenever the design refrigerant is changed, the system must be re-optimized and may require substantive design changes to achieve acceptable performance and reliability. The known substitute candidates for CFC-11 and CFC-12 replacement will require significant equipment and system changes to achieve these objectives. These efforts are actively being pursued by systems and component manufactures with appropriate technical support by ALLIED-SIGNAL.

The extent of the effort and the timeliness can vary significantly by application and by the types of adjustments and redesign imposed by the replacement fluid.

In virtually every area of refrigerant application, this task is underway but incomplete. The phasedown schedule in the current Montreal Protocol already severely taxes the ability of the various end-users to accomplish and incorporate the essential product redesign. Accelerated phasedown will certainly exacerbate an already difficult challenge.

(12e) Signals at EPA and in the halls of Congress that some of the identified alternatives will have insufficient product lifetimes to justify the investment needed for us to produce them and for our customers to develop equipment to use them.

Response:

I believe that this question was answered in 6(B), but briefly we are concerned about what we have recently heard from Congress and the Administration that raises some question about how fast we should continue moving forward. Uncertainty, can never be removed from decision making, however, we certainly can minimize the impact of that uncertainty by waiting to commit the bulk of the $250 million we expect to spend until we understand the shape of the market for which we are developing products.

(12f) High capital needs and an uncertain business climate.

Response:

We feel very strongly that CFCs are not appropriately used as a revenue raiser. We need to generate capital in order to do the research and retooling to ultimately make a new business. Plants in our system which were scheduled to last another 20 to 30 years are becoming obsolete virtually overnight and need to be replaced.

(12g) Threats in the U.S. of auctions or taxes that will divert needed revenue streams from the private sector to the government's general fund.

Response:

In regard to the auction permit system that has been discussed, we feel that it is also unnecessarily disruptive. It is essential that a market exist for these new products when they become available in the early 1990's. The auction system would only be in place for a very short period of time but may destroy the market for the future. The strongest

voices in the economy would be rewarded which may eliminate some beneficial uses of CFCs and their substitutes. I also believe that several questions about the legality of the system also need to be addressed and understood before it should ever be considered.

We also believe that industry in general will find such product specific revenue raising objectionable and a threat to the ability to plan for future capital investment and to be competitive in world markets.

(12h) The need to complete development, evaluation and design of retrofit technologies so the current equipment which relies on CFCs (U.S. investment signs exceeds $135 billion) will serve for its useful life.

What is the status and our time table for overcoming each of these barriers, and how can the government, EPA, DOE, and NIST help in speeding up the process and overcoming these barriers?

Response:

ALLIED-SIGNAL supports the objective of implementing retrofit technologies where feasible to accomplish the objectives of an expedited phasedown of CFCs. We caution, however, that this should not be allowed to interfere with or delay the accomplishment of the primary goal which is to develop and implement permanent, long term environmentally acceptable solutions for future systems.

The current status of retrofit technologies varies dramatically depending on particular hardware and refrigerant properties. Most of this effort must be carried out by the equipment manufacturers with the help of knowledgeable refrigerant producers such as ALLIED-SIGNAL. Even within specific industries, one manufacturer's equipment may be more capable of being retrofit than anothers.

It is our observation that most manufacturers are already addressing this issue. ALLIED-SIGNAL is supporting such efforts wherever possible. It appears that such efforts will be most fruitful once the technology of applying the alternatives to new systems is better advanced. We strongly recommend that the implementation of retrofit technology be regarded as an important, but secondary, objective and that it not be mandated to the detriment of the overall industry effort.

The Federal Government can do much to provide an atmosphere conducive to effecting these changes. Specific examples would include the following:

- EPA could eliminate or reduce the barriers to recycling of existing refrigerants. Pre-emption of unnecessarily restrictive state and local requirements could promote this activity.

- DOE could delay the imposition of new energy efficiency requirements until the final impact of replacements can be evaluated. This would also reduce the dilution of resources of equipment manufacturers so that they can focus initially on replacements and then on retrofit.

- NIST could perform a very useful function by conducting "generic" research on alternate fluids. Some suggestions might be:

    a. developing certified standard thermophysical properties on leading alternatives, resolving discrepancies between various disseminated "engineering quality" data.

b. developing highly accurate mathematical models to represent the thermophysical property data of fluorocarbon mixtures where only pure fluid data is available.

c. developing cycle simulation and experimental confirmation capabilities to evaluate the energy efficiency of alternates.

Q. FROM SENATOR KERRY

(13) DOE currently is in the process of promulgating new regulations for improving the energy efficiency of home applicances. At the same time, refrigerator manufacturers are concerned that they will soon be required to replace CFCs refrigerants. I understand that these substitutes are not as energy efficient. This situation obviously has the potential to have a serious negative impact on the industry.

Can you offer any suggestions for improving the regulatory process to reduce such conflicts?

How can the industry become more constructively involved in the regulatory process?

Response:

As I said in my testimony to this committee and to others, CFCs have many societal uses for which no substitutes exist. This is an example of laudable government initiatives in conflict, one for energy efficiency and the other for environmental protection.

We are working very closely with appliance manufactures but unfortunately there are no easy solutions. CFCs provide the cool temperatures that allow a refrigerator to do its job, but they are also vital components of the foam wall that provide insulation to let it work efficiently.

I don't have an easy answer to this dilemma. I would recommend that the DOE and EPA coordinate their programs in order to minimize the disruption to the appliance industry that may be caused as a result of these initiatives being at crosspurposes. It may be that the timetables under consideration by the DOE need to be adjusted to reflect substitute research.

Q. FROM SENATOR KERRY

(14) It is my understanding that CFC 113 is currently used to clean computer chips. What types of alternatives are being developed in this area? How quickly can new methods be developed and implemented? What impact will this have on the computer industry?

Response:

ALLIED-SIGNAL has developed and announced to the electronics industry in March a new family of low ozone depleting solvents based on HCFC 141b. These new solvents, which would have approximately 1/10 the ozone depletion potential of CFC 113,

could be used in most of the CFC 113 cleaning applications of the electronic/computer industry. Our preliminary tests indicate that it performs as well as or better than the current CFC 113 based solvents.

ALLIED-SIGNAL's timetable calls for the commercial availability of these solvents in mid 1992. This timing is dependent on the successful completion of adequate toxilogical testing and commercial plant construction.

Because the electronics industry is familiar with the performance and reliability of CFC cleaning processes, the change over to a HCFC solvent would generally be viewed by the electronics industry, we believe, as a lower risk and less disruptive than going to other alternative cleaning technologies.

Q. FROM SENATOR KASTEN

(15) Shouldn't we stress the need for an international effort if we're going to control the technology of production of CFCs and their use in end products? Don't we have to guard against adopting a U.S. CFC ban, which could just result in having foreign countries continue to use ozone depleting products and the U.S. importing the end products? This would not only continue the environmental harm, but cause unilateral economic harm to the U.S. Could you comment on this please?

Response:

Allied Signal is firmly committed to a global solution to the problem of ozone depletion. Unilateral sanctions on this subject tend to be counterproductive and be of limited environmental benefit. You have raised several key points in your question that argue against unilateral action.

Our policy is that further reductions in the production and uses of CFCs should occur, but only through the process established by the Montreal protocol. To do otherwise raises a host of trade and competitiveness issues that don't arise if we continue to operate on an international basis.

Q. FROM SENATOR McCain

(16) How does the cost of possible substitute compounds compare with those currently used?

Response:

It is impossible for us to estimate the cost of the substitutes at this time. We have process technology research that is ongoing and pilot plant assessments yet to be made. Without question, however, the cost of the substitutes will be greater than the current cost of the controlled product.

Q. FROM SENATOR McCain

(17) Concerns have been raised that implementation of the Montreal Protocol will result in windfall profits for producers and that the financial gain might discourage companies from marketing substitutes as soon as possible. What are your views on this?

Response:

This issue has been raised a number of times by various people and we have always disagreed with it because it doesn't take into account that businesses operate for the long term, not the short term. We have tried to demonstrate that a race between very large research driven international companies is well underway as a result of the Montreal Protocol. The reason is fairly simple--there is a market that needs to be served waiting for these substitutes.

It's very important that the Committee understand that the market is going to be in a disrupted condition for a relatively short period of time, probably 7-10 years before it is largely changed over to substitutes. We need to maintain a market or else there will be no one to utilize the substitutes. Would it be a smart business decision to so maximize our profits in the short term that we destroy the market for these new products that we are trying so hard to develop and commercialize? I don't think it would be. Just like ever other company involved in the search for substitutes, we want to be the first one with a product in the market. We have no intention of holding back anything from the marketplace that will make a contribution to helping solve the problem of ozone depletion.

Senator GORE. Mr. Arnold Braswell, President of the Air Conditioning and Refrigeration Institute. Welcome.

STATEMENT OF ARNOLD BRASWELL, PRESIDENT, AIR CONDITIONING AND REFRIGERATION INSTITUTE, ARLINGTON, VA

Mr. BRASWELL. Thank you, Senator.

I am President and chief executive of the Air Conditioning and Refrigeration Institute, known as ARI. That is the trade association of our manufacturing industry, and I welcome the opportunity to discuss the challenges presented to producers and to the public by the reduction and possible future phaseout of chlorofluorocarbon refrigerants.

These refrigerants, as you know, are used in a large portion though not the majority of the units manufactured by members of our association, ARI.

Our members, by the way, do not include refrigerator or automotive air conditioning manufacturers.

Our industry endorses the global measures to reduce as rapidly as possible the use of substances which damage the earth's ozone shield. ARI called for international agreement on such measures well before the signing of the Montreal Protocol. We agree with the need to reexamine the current reduction schedule in light of the latest available evidence.

That examination must also consider the world's need for efficient refrigeration and air conditioning systems and the realities associated with converting new equipment as well as the huge world inventory of existing equipment to new refrigerants. The task is enormous, and we must proceed prudently.

This equipment is used widely to preserve food, to keep our large buildings habitable and to support many industrial operations.

Products of our member companies using CFC refrigerants include the following: Centrifugal chiller machines for air conditioning large buildings, produced in the U.S. at a rate between 3,000 and 4,000 per year, with about 80,000 installed nationwide. These units last for 25 years or even more. As Dr. Glas has said, maybe even 40 years in some cases.

Refrigeration equipment used in supermarkets, restaurants, trucks, rail cars and other applications. An unknown number of units, probably over two million, are installed nationwide. These units will last 15 years or more; with replacement of worn components such as compressors or motors, they will last indefinitely.

Electric drinking water coolers, with perhaps six to eight million installed nationwide, and automatic ice makers used in hotels and restaurants, with maybe three million installed nationwide.

We believe that ARI-covered products, the ones I have just talked about, both new and installed, account for about 10 to 15 percent of the total U.S. CFC consumption. That is a rather small percentage.

In referring to CFCs I do not include the hydrochlorofluorocarbons—or the HCFC compounds—which have, as we have heard, very little effect on the ozone layer and are not currently planned for reduction.

HCFC 22 is one of these, and it is the most widely used refrigerant in air conditioning systems. It is a potential alternate to CFC

refrigerants in some other applications, but this will require new or modified equipment. It is, therefore, part of the solution to the ozone depletion problem. For that reason, it would be a mistake—and I agree with Dr. Glas on this point—to begin considering possible restrictions now on this very useful compound. That would be very counterproductive.

But HCFC 22 is not an efficient or economical alternative for some other major applications and, therefore, it would be a mistake also to base CFC reduction plans on the assumption that this alternative, HCFC 22, is readily available for all or virtually all uses. It is not.

The task of converting to alternative refrigerants is daunting, Mr. Chairman. There are known problems with all current alternatives, either with performance or chemical compatibility with materials used in equipment or perhaps with other properties. The toxicity tests will take many years. Little or none of the several new candidate refrigerants have been available for testing by manufacturers up until recently. There is growing belief that a sizeable group of new refrigerants, including mixtures, will be needed.

Manufacturers have been collecting data and conducting research on alternatives to the best of their ability in the last two years. Virtually all of our major manufacturers, acting on the suggestion of ARI, have recently agreed to share most of their research data with industry and the government through the National Institute for Standards and Technology. This is an unusual step and indicates our industry's commitment to get on with this task.

I might add that the chemical companies here at this table also have agreed to share that research to the extent that they can do so.

But our industry cannot do the job alone. There is too much to be done in a short time. We could do it alone if there were plenty of time. But there is some help that can be provided to get on with it faster. We cannot do everything we need to do: (1) to test and prove all of the candidate refrigerants, (2) to select the most suitable and efficient ones for various applications, (3) to design and test new equipment, and (4) to retool for production. The process takes time and money.

Industry would welcome government assistance in research, and there is much that government can do and should do. Most of the R&D work will still be done by industry. ARI has recently initiated an association research program and developed a research plan. The most immediate objective, though not the only one of the plan, is research on alternative refrigerants. The plan defines those tasks best performed by industry and those which could be done by government, and it lays out time schedules.

We have discussed our plan with DOE, EPA and NIST, and they are working informally with us to refine it. NIST has a very important role. At ARI request, NIST has agreed to accelerate its research on refrigerant properties and also to expand its planned data bank on new refrigerants this year if funds can be made available. DOE and EPA may be able to help with this. ARI has agreed to contribute some funds immediately.

The funds needed are small, but the Congress and the administration should provide adequate research funds to NIST and to

other appropriate agencies such as DOE and EPA. Yet the current 1990 budget contains no NIST funds for refrigerant research. This, in our opinion, is a serious omission.

Industry will do its part by sharing data available, by developing and testing new products, and by converting production facilities when the time comes. And industry, through ARI, will work closely with government agencies to help plan and coordinate industry and government research activities.

We must keep in mind the vast inventory of installed equipment which will continue to need servicing with either new or recycled CFC refrigerants until that equipment can be replaced. Many years will be required to replace all of it. We may find substitute refrigerants suitable as "drop-in" substitutes for some of these units, but we do not have proven drop-ins yet, and we may not ever have them for some of this installed equipment, perhaps for most of it. We currently believe that some CFCs will continue to be needed beyond the year 2000.

Summing up, Mr. Chairman, the makers of commercial refrigeration and central air conditioning equipment are working hard to find new refrigerants. It is a big task, and it will take time. We do not have the answers yet.

We must not give up our hard-won gains and efficiency. That would be a mistake. So, we have to look at every possible alternative before we make a final decision on which refrigerants to use.

We need some time and the nation needs time to make this conversion. We also need understanding, and the government has a role to play in this research.

I thank you for the opportunity to discuss this subject, and I will be glad to respond to your questions.

[The statement follows:]

STATEMENT OF ARNOLD BRASWELL, PRESIDENT, AIR-CONDITIONING AND REFRIGERATION INSTITUTE (ARI)

Mr. Chairman and Members of the Subcommitee; my name is Arnold Braswell and I am President of the Air-Conditioning and Refrigeration Institute (ARI). We welcome this opportunity to present our views on the challenges to the producers and users of air conditioning and refrigeration equipment posed by the phaseout of chlorofluorocarbons (CFCs).

ARI is the national trade association representing manufacturers of over 90% of U.S. made central air conditioning and refrigeration equipment. We have about 170 member companies, all manufacturers. In addition to our trade association duties, one of ARI's primary functions has been to develop product rating standards for equipment capacity, energy efficiency, sound and other performance features in order to provide accurate information to consumers. ARI administers some 15 separate rating certification programs for members and non-members of ARI. These programs verify manufacturers product ratings by means of third party independent testing laboratories. ARI product rating directories are common resources for consulting engineers, utilities, HVACR sales and service technicians and many building and construction officials. ARI standards are recognized world wide and are incorporated into many federal, state, and local building codes in the U.S.

ALTERNATIVES TO CFC'S

Products of our member companies which are dependent on CFC refrigerants are as follows:

Product	CFCs Used
Commercial building air conditioning chillers	11, 12, 114, 500
Commercial refrigeration units	12, 502
Mobile refrigeration (trucks, railcars)	12
Drinking water coolers	12
Automatic commercial ice makers	12

While these products use of CFCs as a percentage of total U.S. usage is not great, between 10-15%, they are obviously integral to the American way of life and economy. Our food distribution system depends on them. Most of our large commercial buildings require them. Many industrial processes use this equipment.

There is no question that the ozone depletion issue is a critical global one that we must address as rapidly as possible. The Montreal Protocol is the best way to insure that a global solution is adopted. In ARI's view, it already presents in its current form a major challenge for CFC using industries to adapt their products. In light of recent scientific findings, it appears the Protocol's features will become even more stringent. This in turn poses additional major challenges for our members and for the multitude of establishments currently using CFC equipment.

While progress has been made toward development of non CFC refrigerants, the task is not a problem free one, particularly regarding the large air conditioning and refrigeration systems. In spite of the positive things known about potential substitutes for CFC-11 and -12, the following is true today:

No proven substitute for CFC-11, -12, or -502 refrigerants exists today for commercial air conditioning and refrigeration;

No proven "drop in" replacement refrigerant exists for installed equipment;

The potential substitutes receiving much attention all have known problems associated with performance or materials compatibility;

The research necessary to test and prove the potential refrigerants in time for early commercialization cannot be accomplished by industry alone;

A government role in the transition to non-CFC refrigerants exists and should be strengthened.

Our message to this Subcommittee today is that our industry is doing and preparing to do everything in its power to meet this environmental challenge. We agree with the need to move away from CFCs. We also ask government and the public to recognize the realities that exist as to the steps needed to insure that the nation's need for essential refrigeration and air conditioning can continue to be met uninterrupted. It is important also that interim solutions be avoided so as not to require two major retooling and redesign programs in the next few years.

Our member companies have not been idle. Equipment manufacturers began acquiring data from chemical producers on HCFC-123 and HFC-134a and conducting preliminary laboratory tests more than a year ago. Because of limited quantities available, particularly for 134a, progress has been slower than we would like and has been focused mainly on materials compatibility questions. Some performance testing in laboratory machines is beginning, as well as initial field testing on HCFC-123 in chillers. There continues to be a need for precise, detailed thermophysical data and compatibility data on these two compounds as well as on the additional alternative refrigerants. Companies are doing what they can with resources available, but much remains to be done and help is needed.

The nation would be better served if more of the basic research and testing could be done under government sponsorship in available public or private laboratories. This would permit manufacturers to concentrate their efforts more productively on machine testing, design and development for various applications. Cooperation of this nature, leading to a more efficient division of effort between government and industry, would be in the public interest.

CHALLENGE NUMBER ONE—NEW PRODUCT DESIGNS

Finding suitable alternatives to CFC refrigerants for most of our products, particularly chillers and refrigeration units, is a more complex task than for larger CFC users, such as auto air conditioners, because of the additional materials that contact the refrigerant and the critical aspect of energy efficiency. While much progress has been made in the past two years in development of alternative refrigerants, final solutions, such as "drop in" replacement refrigerants are by no means available. On the contrary, potential alternatives for CFC-11 and -12 refrigerants, namely HCFC-123 and HFC-134a, each present significant technical problems, as

yet unsolved. There is a growing belief among the experts in our industry that HCFC-123 and HFC-134a may not be the final answers; but rather that a larger group of alternative refrigerants, including mixtures, may offer the best solution. The near-azeotropic mixture recently announced by Du Pont may well be in this category.

A major factor affecting the suitability of HFC-134a to replace CFC-12 is its energy efficiency. This is in part tied to the current lack of a compatible lubricant, which is an essential additive to refrigerants in all equipment. Based on the thermal characteristics of HFC-134a as compared to CFC-12, HFC-134a theoretically may run about 8-10% less in energy efficiency. However, actual tests performed at DOE's Oak Ridge National Laboratory (ORNL) on HFC-134a in systems with potential lubricants have resulted in efficiency degradations of 20% and higher. Such a decline in efficiency would not be acceptable.

In the case of HCFC-123, as a substitute for CFC-11 in chillers, there are problems with materials compatiblity. It tends to disintegrate the seals which contain the refrigerant in this equipment. Materials compatibility is an extremely important issue in developing alternative refrigerants. This is especially true in hermetic compressor systems such as centrifugal chillers. Unlike open compressors, used in automobile air conditioners, hermetics expose the refrigerant to motor winding insulation, which can decay if it comes in contact with an incompatible material. To date, the compatibility problem with HCFC-123 has not been solved.

HCFC-22 as an alternative refrigerant merits special attention and comment. It is the most widely used refrigerant today. Nearly all of our residential and many of our commercial air conditioners use it. A significant portion of industrial and commercial refrigeration systems use it. It is not a suitable refrigerant for most large chillers or for a significant number of refrigeration applications. It cannot be used in equipment designed for other refrigerants without major modifications or replacement of equipment. For these reasons we cannot rely solely on HCFC-22 as a satisfactory alternative for CFC refrigerants in many important applications.

But HCFC-22 is indeed a partial solution, and it will be increasingly used in new equipment designed for it. For this reason and because so many of our current systems depend on it, the status of HCFC-22 should be protected. In fact, it must be protected if we are required to accelerate the reduction schedule for CFC production. While HCFC-22 does have a small depletion factor and is a greenhouse gas, many other alternative refrigerants are in the same category.

During the next decade it will be difficult enough to find ways of switching from the CFC refrigerants. To require a reduction of HCFC-22 usage at the same time would present impossible conditions. We simply could not do it. We must be able to use this proven refrigerant in current and expanded applications for the foreseeable future. It would be most counterproductive to do otherwise.

While HCFC-123 and HFC-134a hold much promise because of their relative thermal performance characteristics and their likely low toxicity, their potential contribution won't be fully understood until products are field tested using them. Field tests have not begun at a significant level yet because of the lack of availability of the compounds.

The status of 123 and 134a therefore has lead our members to broaden their search for potential alternatives. Several other potential refrigerants are being examined, such as those in the following table:

Potential alternatives:	*Replaces*
125	502
124	114
32	502
143A	502
134	12
152a (in mixtures)	12
Mixtures (near, and non-azeotropes)	11, 12, 502

CHALLENGE NUMBER TWO—INSTALLED EQUIPMENT

The vast majority of the large air conditioning chillers used to cool large office buildings, hospitals, and other commercial establishments rely on CFC refrigerants. There are about 80,000 installed in the U.S. which use CFC-11 and -12 and these systems have useful lives exceeding 25 years. A chiller installed today will therefore still be in use in the year 2014. There currently exist no "drop in" replacement refrigerants for these systems, which mainly rely on CFC-11. HCFC-123 is a promising alternative for new systems, but for installed equipment, it poses problems, par-

ticularly for those with hermetic compressors. We do not yet know that these problems can be overcome.

The ternary blend announced recently by Du Pont may well be a suitable substitute refrigerant for existing residential refrigerators and possibly for automobile air conditioners which rely on CFC–12. It does not appear to have potential for installed centrifugal chillers. It may or may not be suitable for commercial refrigeration units currently installed. Without such an alternative, major replacement of installed equipment would be necessary if supplies of CFC–11, –12, and –114 were not available. We therefore believe that supplies of CFC–11, –12 and possibly –114, –500, and –502 will be needed beyond the year 2000. Even with a proven substitute refrigerant available, if major system replacements are required there currently does not exist sufficient capacity within the industry to replace existing equipment rapidly. Even if some centrifugal chillers are replaced by screw chillers using HCFC–22, a feasible alternative in some applications, there is still a capacity limitation.

We are hopeful that the demand for CFCs for this installed equipment can be tempered in the future by better service practices, particularly the recovery and recycling of CFCs. To this end, ARI has recently published Standard 700–88, which defines the acceptable level of contaminants for recycled refrigerant. However, even with recycling, our current belief is that some production of CFC–11, –12, –114, and –502 will be needed beyond the year 2000 to service installed equipment.

SOLUTIONS

ARI has been most recently called upon by its membership to coordinate industry efforts in responding to four major global issues. These are (1) the need to reduce or eliminate use of CFC-based refrigerants stratospheric ozone depletion, (2) the need for the U.S. industry to remain competitive in response to global technological advancements, (3) the need to strive for further advances in energy efficiency, and (4) the increasingly important issues of building environment and indoor air quality.

All four of these issues are major public policy issues as well, and therefore require a federal governmental role. All of these issues also have a significant technological basis and generate the need for critical research and development.

ARI RESEARCH PLAN

ARI has therefore initiated a Research and Technology program and prepared a research plan to address the issue of alternatives to CFC refrigerants, energy efficiency, and building environment. Our members have concluded that this unprecedented new effort is needed to meet the challenges of global technological developments and competition.

We believe our industry's ability to succeed in this plan—and the nation's ability to benefit from it—depends greatly upon federal cooperation and support. We view the federal role as critical. This is most immediately true in the area of alternative refrigerant research.

The objective of the ARI plan is to develop a long-term refrigerant research program that meets industry needs and takes into account the research and testing activities of all organizations involved, including chemical producers, equipment manufacturers, government agencies, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and university laboratories. The intention is to explore a number of refrigerants, including mixtures, to facilitate selection of the most suitable refrigerants for future applications. The program will also recommend a process for similar industry/government cooperation in long-term research on energy efficiency and building environment technologies. Major objectives are to advance our technology and keep industry competitive.

ARI's goals for refrigerant research are:

1. To achieve equal or better energy efficiency in HVACR equipment.
2. To use environmentally-sound refrigerant substitutes.
3. To assure prompt action in all use sectors in light of the timeframe for CFC phaseout.
4. To protect the safety of industry personnel.
5. To protect the stratospheric ozone layer.

Some actions have already been taken to implement the plan. We have held discussions with staff members of EPA, DOE, and NIST. All have indicated their interest in cooperating, on a long-term basis.

At the request of ARI, the National Institute for Standards and Technology (NIST) has agreed to expand the functions and scope of the data assembled by its Office of Standard Reference Data. It will collect, merge, and provide on request the most recent evaluated thermophysical and performance data available for new re-

frigerants as well as information on chemical compatibility with equipment materials. NIST will also seek ways to accelerate planned refrigerant testing and development models to provide detailed thermophysical property data on the new refrigerants.

ARI asked its member companies to agree to release their refrigerant research data and provide it to NIST for evaluation and inclusion in the data bank. Thirteen major companies of ARI have now agreed in principle to share much of their data, and agreement by others is expected. This action should aid the rapid accumulation of refrigerant data and will permit NIST, the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE) and others to focus research efforts more effectively. In the near future, NIST expects to issue guidelines and instructions for data submission to industry companies and others.

ARI will contribute $50,000 to the limited 1989 funds available to NIST in rapidly building up the refrigerant data in the NIST data bank and developing standard test procedures. EPA and DOE officials have also agreed to explore the allocation of additional 1989 funds to NIST to accelerate its refrigerant research. A responsible funding level for FY90 is needed too.

FEDERAL ROLE

As mentioned above NIST has already established itself as a resource in its ability to collect and analyze existing refrigerant research data. They can also assist in the transition away from CFCs in two other key areas. The first is in determining the thermodynamic and thermophysical (transport) data on each alternative refrigerant or blend. Chemical producers will not be able to provide this information in detail on all potential refrigerants in sufficient time. It's too big a job.

This data is needed on 134a, 123, 134, 125, 124, 32, 143A, 152A, 141b, and several possible mixtures, such as 134/134a/152a. The best measuring equipment, modeling facilities, and personnel for this task are in NIST. They have begun this work in FY89 on HCFC-123 and HFC-134a with some direct funding and some provided by DOE, in the neighborhood of $300,000. The work may be expanded in 1989 with some reprogrammed funds of DOE and EPA to include HFC-125 and CFC-141b. But this project must be strengthened to examine more substitutes quickly. This could be possible if some private and university laboratories with the proper equipment and personnel were allowed to participate.

MATERIALS COMPATIBILITY

A second major area for government involvement in alternative refrigerant research relates to the compatibility of alternative refrigerants with materials. Some large air conditioning and refrigeration manufacturers have begun testing alternative refrigerants such as HCFC-123 and HFC-134a in existing equipment. Not only must the refrigerant be tested for performance, it must also be tested for its compatibility with various materials used in the manufacture of the product and with various lubricants. Each combination of a potential refrigerant, a possible lubricant, and a specific material must be tested. Sufficient testing laboratory capacity does not exist in our industry to do such testing on the many combinations of potential refrigerants and lubricants in the needed timeframe. This is another area where federal research and development facilities or resources can help. However, before this kind of testing can be done in large scale, a standard test methodology must be established so the end product of the tests performed inside is usable. NIST is uniquely suited to aid in this effort. We have established a committee of industry experts to lay out guidelines for NIST to develop such a methodology, but they must have the proper resources.

PERFORMANCE TESTING

Another area for a federal role is in preliminary performance testing, particularly with refrigerant blends. DOE's Oak Ridge National Laboratory (ORNL) has already performed some preliminary performance tests on HFC-134a and nonazeotropic mixtures in refrigerators. This kind of work should continue. Manufacturers will also be involved in performance testing—some are now—but they will need to have the best possible preliminary information to help them narrow the focus of their research.

FULL SCALE TESTS

The ARI Research and Technology Plan lays out eleven separate aspects to the comprehensive testing and research and development that must be accomplished

before a substitute refrigerant can be used commercially. There is a significant federal role in some of the initial steps as mentioned above. These steps are the initial steps, and therefore are the most pressing. They are non-competitive areas. Obviously the production of refrigerants and field tests of products and other commercialization steps are for the private sector. They are the most costly and the most proprietary. However, the federal role is critical in getting through the early stages so that the later work can move forward early.

ENERGY EFFICIENCY

Clearly the greenhouse issue has shown how intricately involved the environmental and energy concerns are. Solutions to the problems of ozone depletion must not exacerbate the potential for the greenhouse effect. Most alternative refrigerants are greenhouse gases and can also contribute indirectly to the greenhouse effect if they are less efficient by resulting in an increase in energy consumption compared with current CFC reliant products. It is possible that some refrigerant mixtures may offer increased efficiency over CFCs, therefore reducing the indirect greenhouse effect. However, this work on mixtures is complicated and involves additional concerns such as flammability. Solutions to the greenhouse effect affecting refrigerants will take more time and government research should continue with adequate funding. Manufacturers in today's global economy do not want to adopt a manufacturing solution to the ozone issue, and then have to abandon it a few years later because of the greenhouse issue. That would be damaging. These issues therefore require a long-term effort between the public and private sectors to determine more precisely the relation of refrigerants to the greenhouse effect both directly and indirectly, and to develop workable solutions.

I wish to restate our industry's determination to help solve this environmental issue. But we must all accept reality. It takes time—and resources—to convert our manufacturing processes and the vast inventory of installed equipment to new refrigerants. We can't begin the process until we can determine for sure which refrigerants to use.

Government assistance is needed to help identify the refrigerants. If we're looking to accelerate the scheduled reduction of CFCs, then it is necessary now to expand and accelerate federal research and testing in cooperation with industry. If this is truly a major environmental issue it would make sense to do that. With some 30 billion dollars in the budget for federal research and development activities, it would be appropriate to authorize much more than the current small amounts allocated to this effort.

I will leave you with a final thought for future contemplation. At some point in the future when production of CFC compounds reaches a very low annual level, market-based allocation systems may become ineffective in permitting the limited quantities to be used in the manner most beneficial to society. If that occurs, the Administration or the Congress will need to consider which applications are to receive priority in use of these chemicals. It would be wise to begin thinking soon about the relative societal values of the various uses.

I thank you for this opportunity and will be happy to address your questions.

[The following information was subsequently received for the record:]

ANSWERS BY ARNOLD BRASWELL
PRESIDENT, AIR CONDITIONING AND REFRIGERATION INSTITUTE
TO WRITTEN QUESTIONS IN SENATOR GORE'S LETTER OF MARCH 21, 1989

Question 1 (Senator Gore): Do your members believe that there will be delays in choosing energy-efficient CFC substitutes if NIST does not alter its schedule for producing high quality thermophysical data, but instead continues to give priority to use of its equipment to research being conducted for the Gas Research Institute on gas metering and for NASA/DOD on the space aeroplane?

Answer: ARI has asked NIST to accelerate its schedule for obtaining thermophysical data. We have been told that this can be done. I am not in a position to judge whether other NIST commitments will delay the research activity relating to refrigerants.

Question 2 (Senator Gore): Is ARI concerned about how various consortia of other nations sponsored by governments will affect the competitiveness of U.S. industry in air conditioning and refrigeration?

Answer: ARI members are indeed concerned that government-supported research in other nations will improve the competitiveness of foreign air conditioning and refrigeration products in the world market. ARI has developed a research plan which, with appropriate government support, will help to advance our industry's technology and help keep our industry products competitive. It was principally our industry's concern with the pace of foreign research that led ARI last year to establish a research and technology program, the first such program undertaken by our industry.

Question 3 (Senator Gore): Could the industry absorb about $20-30 million of R&D funds from the proposed fees being put on regulated CFCs?

Answer : ARI does not see the need at present for regulatory fees on controlled CFCs, but if such fees are imposed we believe that the revenues should be used to support appropriate research and development programs. Equipment manufacturers represented by ARI could put substantial funds to good use in various types of research to facilitate the transition to alternative refrigerants. There is much research and testing needed to identify new refrigerants and evaluate them for performance, compatibility with materials, safety and durability. The funds required for such a program require analysis but could approximate 20-30 million dollars a year. Other elements of the refrigeration and air conditioning industry (refrigerators, auto air-conditioners, foam producers, refrigerant producers) could also use substantial funds.

Question 4 (Senator Hollings): Any comprehensive strategy to cut CFC emissions will require developing CFC alternatives, developing new technology, and instituting CFC recycling programs.

- Which steps do you think will yield the largest reduction in emissions most quickly and for the least effort?

- Are there federal laws and regulations that are making cutting CFC emissions more difficult?

Answer (Part 1): Globally, the largest and earliest reductions in emissions could be achieved by banning the use of CFCs as aerosol propellants. In this country, where aerosols have already been restricted, there are few easy solutions. However, early and significant reductions may be possible in manufacture of foam, use of CFCs as industrial cleaners, and servicing practices for automotive air conditioners. Some reductions can also be made by reducing leaks and improving servicing practices for commercial refrigeration and air conditioning equipment.

Answer (Part 2): While I know of no federal laws and regulations which inhibit control of CFC emissions, there are a growing number of state regulations and interpretations which inhibit recovery and recycling of CFC refrigerants. A number of states incorrectly treat used CFC refrigerants as hazardous substances, thereby making it burdensome to recover and transport refrigerants to central locations for recycling. This leaves on-site emission as the easiest alternative.

Question 5 (Senator Hollinngs): I'd like to get your opinion of which parts of the transition to CFC replacements will be most difficult.

- Who do you think has the tougher job, the CFC manufacturers or the CFC users?

- Many different industries use CFCs. You represent makers of large refrigeration and air conditioning systems but CFCs are also used in household appliances, in foam blowing, and in computer chip making. Of the various users of CFCs, which ones do you think will take the longest to stop using CFCs?

Answer (Part 1): I believe that both the CFC manufacturers and the equipment manufacturers will have tasks of equivalent difficulty. Both of them will have to work together. Chemical manufacturers must provide adequate quantities of new substances and mixtures to the equipment manufacturers for research and testing. They must also conduct the lengthy toxicity testing required for these new compounds. Equipment manufacturers must test the new refrigerants for performance and compatibility, design new equipment, and then get it into production. As CFC refrigerants are phased out, service technicians in the field will have an increasingly difficult job keeping the installed inventory operating. Unless substitute refrigerants are found which can be used in the old equipment, it will no longer be serviceable and will have to be replaced. Government-funded research is needed to help find acceptable temporary substitutes for use in the old equipment while manufacturers concentrate on developing new products designed for new and different refrigerants.

Answer (Part 2): I believe that the large air conditioning chiller machines and the large commercial refrigeration systems will take the longest time to convert completely away from CFCs. Many of these systems last for 25 years or more. Phasing out CFCs in these machines

before they are replaced would require finding substitute refrigerants which will perform satisfactorily in them with little or no modification of the equipment. This is regarded as unlikely for the majority of the inventory.

Question 6 (Senator Hollings): A CFC phase-down will create new markets for CFC-free technology. I understand that Japanese air conditioning and refrigeration companies are spending quite a bit more than American firms on developing this new technology.

- Do you have any figures on the investments of U.S. and Japanese firms in this area?

- Are we going to let the Japanese take this market just like they have taken so many others?

Answer (Part 1): ARI has a current estimate of research and development expenditures by U.S. equipment manufacturers who belong to ARI. It approximates 20 million dollars in 1989 and will increase by 50% or more in 1990 and subsequent years. We do not have information on funds being invested by Japanese firms in this area.

Answer (Part 2): Our manufacturers intend to remain the leading world producers of this equipment and they are capable of doing so. U.S. laws and regulations affecting our industry and its products will have a great deal to do with this. Congress and the administration are capable of helping or damaging our industry's capability to remain globally competitive.

Question 7 (Senator Hollings): The National Institute of Standards and Technology has a program to develop new air conditioning technology that does not use CFCs.

- Have the members of your association found this program useful? Why?

- Should the Congress consider expanding it?

- How else can federal R&D efforts assist your industry as it makes the transition to CFC alternatives?

Answer (Part 1): Our industry considers NIST research on refrigerant properties to be extremely important and we have recommended that this work be accelerated and expanded. The NIST experimental work on new refrigeration technology may or may not provide usable technology; it is too early to tell.

Developing all of the technology involved in the task of converting to non-CFC refrigerants is a massive effort requiring the cooperation of equipment manufacturers, chemical manufacturers and organizations such as NIST as well as other government and private research entities.

ARI has urged NIST to accelerate and expand its refrigerant research activities as well as its planned program of assembling a repository of

technical information on new refrigerants. In fact, ARI is contributing funds in 1989 to permit expansion of this NIST activity for the benefit of the industry and has obtained agreement in principle by ARI members to provide non-proprietary refrigerant research data to the NIST repository.

Answer (Part 2): Congress should consider expanding the funds provided to NIST for refrigerant work, because their planned funding is inadequate. (No funds are in the 1990 budget for refrigerant activities). ARI believes that NIST should be provided with as much as three million dollars per year for the next three years for the purpose of research and technical assistance to industry in this area.

Answer (Part 3): There clearly are other ways in which the federal government could assist our industry greatly in expediting the transition to CFC alternatives. If there were plenty of time available, the industry could accomplish virtually all of the required research and development activity without federal involvement. However, we are facing the possibility of rapid phase-out of CFCs and the requirement for immediate development of new equipment using alternative refrigerants. This is a monumental task, because the number of candidate refrigerants is limited and there are strict requirements which they must satisfy.

In addition to the research on thermophysical properties being conducted by NIST, there is a pressing need for assistance in evaluating the compatibility of various new refrigerants with the many different materials and lubricants which are used in refrigeration and air conditioning systems. We have already learned that some of the promising refrigerant candidates have compatibility problems with the materials used in current equipment. Extensive additional research is needed and must be accomplished rapidly if we are to quickly identify the most satisfactory new refrigerants and then begin the detailed design and development work for the equipment which will use these refrigerants.

ARI has developed a research plan which addresses the research activities required to answer the compatibility questions. If federal funds were made available, ARI could administer a research program that would provide needed information to the industry on the chemical compatibility of new refrigerants with the materials, including lubricants, used in industry equipment. Such a program would be of immense benefit in expediting solution to the difficult questions which we face.

Question 8 (Senator Pressler): How much of an investment must your industry make in developing technology to use CFC substitutes? Might developing countries produce equipment that uses old CFCs if we abandon this market unilaterally?

Answer: No one can estimate now the total investment our industry must eventually make in developing technology to use CFC substitutes. It will most certainly be in the hundreds of millions of dollars, and this does not include the costs of retooling for producing new equipment.

When our nation stops making CFC equipment it is possible and perhaps even likely that some developing countries, particularly those which are not signatories to the Montreal Protocol, will continue to produce such equipment. This assumes that they will have an adequate source of CFC refrigerants. However, if the major industrialized nations switch to new refrigerants the technology for equipment using these refrigerants will soon spread to the developing countries as well. If there is an agreed environmental need to stop producing CFCs on a global basis, we should not be deterred by the possibility that some developing nations will delay conversion to the new refrigerants.

Question 9 (Senator Pressler): Will users of CFCs be able to "drop substitutes into" their equipment?

Answer: At this time we do not know of any substitute refrigerants which can be satisfactorily dropped into existing CFC equipment without any modification. It is possible that such substitutes can be found but most industry experts regard this as unlikely. It is more likely that all equipment will require some modification before it will operate satisfactorily and efficiently with a different non-CFC refrigerant. In some cases the modifications may be minor; in others they will be extensive. Because there is a vast inventory of CFC equipment installed, particularly large air conditioning machines and commercial refrigeration equipment, and because this equipment lasts for many years, the search for drop-in substitutes should have high priority. This is an area in which the federal government could be very helpful by conducting experiments and field tests on federal installations. Equipment manufacturers cannot pursue this type of research activity while heavily committed to developing new equipment for future production with new refrigerants.

Question 10 (Senator Pressler): Should we accelerate the schedule set forth in the Montreal Protocol? Should we take unilateral action?

Answer: Our industry will support acceleration of the schedule set forth in the Montreal Protocol if environmental scientists and political leaders are convinced that it is absolutely essential to do so in order to protect the environment. It will be important to weigh the economic and other effects of accelerated CFC phase-out against environmental needs in deciding on the extent of acceleration to be agreed upon. It would be a mistake, however, to take unilateral action. All efforts should be directed toward solving this problem on a global basis with at least the major industrialized nations participating.

Question 11 (Senator Pressler): What incentives should the federal government provide to make CFC substitutes affordable and useful?

Answer: I do not know of any federal incentives which are needed to make CFC substitutes affordable and useful. However, there may be a role for federal incentives of some sort to promote wide-spread reclaiming and recycling of used refrigerant. This is a matter which deserves study.

Question 12 (Senator Kerry): The following barriers to replacing CFCs

were listed by Dr. Glass in his prepared testimony:

— Incomplete or inconsistent thermodynamic and transport property information on all of the identified alternatives.

—Incomplete development of equipment that can use the alternatives.

— Signals at EPA and in the halls of Congress that some of the identified alternatives will have insufficient product lifetimes to justify the investment needed for us to produce them and for our customers to develop equipment to use them.

— High capital needs and an uncertain business climate.

— The need to complete development, evaluation and design of retrofit technologies so the current equipment which relies on CFCs (U.S. investment alone exceeds $135 billion) will serve for its useful life.

What is the status and our time table for overcoming each of these barriers, and how can the government, EPA, DOE and NIST help in speeding up the process and overcoming these barriers?

Answer: The timetable for overcoming the barriers described by Dr. Glas in his testimony will depend upon the CFC phase-out schedule and upon the completion of such activities as toxicity testing of new refrigerants. The government can help speed up the process by (1) establishing clear policies on refrigerant phase out and then sticking with these policies; (2) by avoiding burdensome CFC control regulations (such as auctioning consumption rights) which would disrupt the market and create artificial barriers to efficient distribution of the declining supply of CFCs; and (3) by conducting research and providing research funds to assist industry in identifying and proving the new refrigerants which will be needed.

Question 13 (Senator Kerry): DOE currently is in the process of promulgating new regulations for improving the energy efficiency of home appliances. At the same time, refrigerator manufacturers are concerned that they will soon be required to replace CFC refrigerants. I understand that these substitutes are not as energy efficient. This situation obviously has the potential to have a serious negative impact on the industry.

— Can you offer any suggestions for improving the regulatory process to reduce such conflicts?

— How can the industry become more constructively involved in the regulatory process?

Answer (Part 1): Resolution of conflicting or competing objectives in the regulatory process is a matter which necessitates informed discussion among the regulatory agencies and the Congress, leading to judicious decisions which take account of all needs. Important in this

decision process is recognizing up front which objectives are conflicting or competing with each other. That recognition has been missing from much discussion on the ozone depletion issue.

Answer (Part 2): I believe that the industry is constructively involved at the present time in the regulatory process.

Concerning efficiency standards, air conditioners which will be required to meet 1992 efficiency standards of the National Appliance Energy Conservation Act (NAECA) use HCFC-22 as a refrigerant. This refrigerant is not scheduled for reduction and should not be considered for control or reduction since it has a negligible effect on the ozone layer. It is also the fall-back refrigerant for many applications currently using CFCs if better alternatives cannot be found.

Question 14 (Senator Kasten): Shouldn't we stress the need for an international effort if we're going to control the technology of production of CFCs and their use in end products? Don't we have to guard against adopting a U.S. CFC ban, which could just result in having foreign countries continue to use ozone depleting products and the U.S. importing the end products? This would not only continue the environmental harm, but cause unilateral economic harm to the U.S. Could you comment on this please?

Answer: It would be very damaging and counter-productive for the U.S. to mandate the phase-out of CFC compounds at a faster rate than that accepted by other major nations. It would definitely cause economic harm to the U.S. industry. All efforts should be directed at securing a broad international agreement on the phase-out schedule.

Question 15 (Senator McCain): What percent of ozone depleting CFCs are used for air conditioning and refrigeration?

Answer: It is difficult to estimate accurately the total quantities of CFCs used for central air conditioning equipment and commercial refrigeration equipment included within the scope of ARI. The problem is that most of the consumption, perhaps 80%, is in field servicing to replace refrigerant quantities depleted by leakage or removed from equipment in the process of repair. ARI estimates that 10-15% of the total CFC consumption in this country is used in the types of equipment covered by our association. These are centrifugal air conditioning chillers; commercial refrigeration equipment used in restaurants, super markets, warehouses, industrial applications and transport containers; automatic commercial icemakers; and electric drinking water coolers. With improved methods of leak detection and prevention, and with an improved nationwide capability for reclaiming and recycling CFC refrigerants, I believe that total consumption for these products could be reduced eventually to 50% or less of current consumption.

Question 16 (Senator McCain): What effect will the 50 percent reduction in CFC production mandated by the Montreal Protocol have on the air conditioning and refrigeration industry?

Answer: The 50% reduction in CFC production scheduled for 1998 will

have a significant impact on the air conditioning and refrigeration industry if the largest consumers of CFCs have been unable to find alternatives which permit them to reduce their consumption by significant amounts. If such alternatives are developed the impact upon our industry and the public will be minimal, particularly as the industry begins producing new equipment using alternative refrigerants.

Question 17 (Senator McCain): What efforts is the industry making to improve CFC conservation, reclamation and responsible field practices to reduce ozone depleting emissions?

Answer: The industry is undertaking various efforts to improve conservation and responsible field practices to reduce CFC emissions. Manufacturers are designing equipment which will be less likely to leak and will be easier to service. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) is developing guidelines for field practices designed to reduce CFC emmisions. Several manufacturers are producing refrigerant recycling equipment which can be used in the field to permit reclaiming and reusing contaminated refrigerant removed from systems.

Question 18 (Senator McCain): Do you know if students at air conditioning and refrigeration trade schools are made aware of the environmental problems of CFCs and taught how to handle these compounds conservatively?

Answer: ARI does not have detailed knowledge of the extent to which trade schools are being taught how to handle CFC compounds in order to reduce emissions. However, ARI plans in the near future to distribute an addendum to the ARI Curriculum Guide for trade schools which will recommend inclusion of such training.

Question 19 (Senator McCain): What could we do to improve these efforts?

Answer: ARI believes that effective efforts are underway to make technicians aware of the need for handling CFCs properly.

Question 20 (Senator McCain): What can we do to better reclaim CFCs contained in cars, air conditioning units and refrigerators which are scrapped?

Answer: CFC refrigerants in large air conditioning units will be reclaimed as a matter of course when such units are scrapped, particularly if the price increases or if reclaimed refrigerants are excluded from control as they should be. Reclaiming the small amounts contained in scrapped refrigerators and automobiles will be more difficult to insure. The best way to significantly reduce automobile emissions is to find a new refrigerant. The best way to reduce emissions from refrigerators is to find new insulation, since 80% of the CFC material in a refrigerator is in the foam insulation. The refrigerant in the foam as a practical matter cannot be recovered.

Question 21 (Senator McCain): I know that it is very important to CFC users that substitutes are "drop-in". For the record, can you explain

what is meant by a "drop-in" substitute and why it is important?

Answer: A "drop-in" substitute refers to a refrigerant which can be used in an installed piece of equipment without any equipment modification. The term does not apply to refrigerants used in redesigned equipment. The development of "drop-in" substitute refrigerants is critically important for commercial refrigeration and air-conditioning equipment because there is such a vast quantity of this equipment already installed. These machines will last for many years and will require servicing with CFC refrigerants from time to time unless suitable substitute refrigerants can be found. If CFC refrigerants are phased out by the end of the century and we cannot find "drop-in" substitutes for this equipment, the industry will have insufficient production capacity to replace all of the equipment before it goes out of service due to lack of refrigerant. This could result in shutting down refrigeration equipment in supermarkets, restaurants and other essential facilities and in shutting down large chiller machines used for essential cooling in office buildings, hospitals, hotels and other large buildings. There are currently no proven "drop-in" substitute refrigerants.

Question 22 (Senator McCain): How much time is needed for property, materials and toxicity testing before we can be sure a substitute is workable?

Answer: One of the principal delays to be overcome in testing new refrigerants is establishing a production capability to produce the quantities required for full scale testing and development. Toxicity testing takes thousands of pounds. Preliminary testing for refrigerant use will take hundreds or thousands of pounds while field testing in equipment will require additional thousands of pounds. It takes time to set up a pilot plant for quantities of this amount and the production costs are high. Once such quantities are available complete testing of properties and materials compatibility may take from two to four years depending upon difficulties encountered. Full scale toxicity testing will take five years or more, although it may not be necessary to complete the full range of toxicity tests before the refrigerant can be selected for use in certain applications and equipment design can begin.

Question 23 (Senator McCain): Is it proper to assume that if further reductions in CFCs are required, without the development of "drop-in" compounds, then CFC users will have to re-tool factories to accommodate nondrop-in substitutes which may be developed?

Answer: Yes, it is proper to assume that equipment manufacturers will have to retool to produce new equipment which uses alternative refrigerants. The extent of this retooling will depend upon how extensive are the design differences in comparison with the CFC equipment.

Question 24 (Senator McCain): Considering the cost, you would agree then that "drop-in" substitutes are a commercial as well as an environmental imperative?

Answer: I would agree that "drop-in" substitutes are a commercial imperative if a total phase out of CFC production by the end of the century is mandated. As to whether or not they are an environmental imperative, this depends upon whether or not it is mandatory to reduce CFC production to zero at an early date. If we cannot find "drop-in" substitutes, then we may find it necessary to continue producing a small amount of CFCs for refrigerant use to support the installed inventory (perhaps 5% or less of current CFC production) for a few more years after other uses are terminated. The alternative would be to shut down a lot of equipment, an action which would have severe economic consequences.

Question 25 (Senator McCain): Is there any indication that foreign companies are making any headway in the development of substitutes?

Answer: Foreign companies are beginning to test alternative refrigerants and some are believed to be about at the same level of development as U.S. companies.

Question 26 (Senator McCain): Do you believe that in light of the environmental and commercial importance of this issue, the federal government can and should increase its efforts in assisting the private sector to develop safe substitutes?

Answer: ARI believes that the federal government definitely can and should increase its efforts to assist the private sector to develop safe substitutes. This can best be done by providing federal funding for industry research programs and by increasing government research support.

Question 27 (Senator McCain): As you know, the Department of Energy, Environmental Protection Agency, Department of Commerce and the Department of Defense each have money and/or facilities for work on CFCs. I have proposed the establishment of a public/private sector task force to help devise, implement and coordinate federal efforts to facilitate the development of and transition to safe CFC substitutes. The task force would also examine ways we can reduce ozone depleting emissions through enhanced reclamation and conservation. Do you believe such a measure has merit?

Answer: There is a need for effective cooperation among federal agencies and departments to assist in the transition to alternative refrigerants. For example, there are federal facilities where substitute refrigerants could be tested in existing federal equipment to determine the suitability of these substitutes under field test conditions. With regard to facilitating the development of alternative refrigerants, our industry believes that some of the government-funded research and development work necessary to accomplish this could be effectively administered through the industry trade associations with federal funding support.

ARI would have no objection to participating in a public/private sector task force or coordinating committee, should one be formed, preferably one that is established as a vehicle to improve communication and avoid duplication of effort. There is a risk that such a task force could operate in ways to obstruct rather than expedite progress in the search for CFC alternatives. It would be important to set it up properly so that it serves as a communicative and coordinating mechanism rather than as an executive body or an additional layer of bureaucracy with veto power.

Senator GORE. Thank you very much. We have had three excellent statements, and I want to say that there is a long history to this issue, but it is certainly good to hear witnesses who are quite well aware of the nature of the problem and who are committed to doing something about it.

There are disagreements among us about how quickly we can or should move to eliminate all these chemicals, but I appreciate the overall thrust of your remarks.

Dr. Glas, let me see if I understand DuPont's position. Your company is committed to completely halting CFC production by the year 2000 in the United States?

Dr. GLAS. That is the deadline.

Senator GORE. Is that a complete halt to CFC production overseas as well?

Dr. GLAS. Yes.

Senator GORE. Now, when you say it is a deadline, what do you mean by that?

Dr. GLAS. A deadline is a deadline. No later than.

Senator GORE. So, you anticipate a complete halt to CFC production worldwide by the year 2000?

Dr. GLAS. The turn of the century is 2001, but a one-year difference will not make that significant a point.

Senator GORE. Actually it will. It will be an extra ten years.

Dr. GLAS. Not by that time. The releases will be so small by that time. But it is a moot point. The turn of the century is what we said, and that is what we mean.

Senator GORE. Mr. Traflet, what about your company?

Mr. TRAFLET. Allied has in essence the same timetable. Industry and government may decide that there is no way that we can do away with all CFCs by that time, the halogenated materials and require that some be supplied.

Senator GORE. What percentage of your business, what percentage of Allied-Signal's business involves CFC production?

Mr. TRAFLET. It is a very small percent. We are a $12 billion company, and this is in the hundreds of million dollars of sales.

Senator GORE. Excuse me?

Mr. TRAFLET. This is in the hundred millions of dollars of sales out of $12 billion, so it is a small percentage of our total business.

Senator GORE. And for DuPont?

Dr. GLAS. Something less than 2 percent.

Senator GORE. Now, Mr. Braswell, you are president of this Air Conditioning and Refrigeration Institute and you are not a manufacturer. You represent the makers of equipment that calls for the use of CFCs, is that correct?

Mr. BRASWELL. That is correct.

Senator GORE. There is a lot of that equipment being sold right now every day that will require CFCs on into the future, correct?

Mr. BRASWELL. Yes.

Senator GORE. I was reading an article in a magazine called The New Scientist of February 11th indicating that China is now being sold a great deal of refrigeration equipment that will require a tenfold increase in their consumption of CFCs by the year 2000. Are you familiar with that?

Mr. BRASWELL. I am not familiar with the numbers, but I am certain that the Chinese are increasing their use of equipment because they have in the past had very little of it.

Senator GORE. And that they will be using by the year 2000, according to this projection, be using as much CFCs as the United States currently is, and we are the largest user now.

Mr. BRASWELL. Well, I could not confirm that. I would be somewhat skeptical of that. That is maybe a remote possibility.

Senator GORE. I will submit this without objection. I will put that article in the record.

Now, let me get a clear picture of what the total volume of CFCs in the United States is by particular category. What is the largest use to which we put CFCs?

Dr. GLAS. I showed you the largest use on the chart. That is refrigerants. And I also showed the market segments. That is 450 million pounds roughly.

Senator GORE. Wait a minute. Before we get to refrigerants, refrigerants is what percentage of the total CFC use?

Dr. GLAS. CFC use is about 700 million pounds per year in the United States.

Senator GORE. That is total CFC use?

Dr. GLAS. Yes.

Senator GORE. What percentage of that is used for refrigeration?

Dr. GLAS. 450, over 700, 60 percent.

Senator GORE. What is the next largest use?

Dr. GLAS. The segment we call the blowing agent segment. It is the segment where industry uses 11 or 12 or 113 to form the foams, inflexible foams cushioning insulation products. That is of the order of something slightly more than 200 million pounds.

Senator GORE. 200 million. What is the next largest?

Dr. GLAS. What we call the cleaning agent segment where 113 and to a smaller extent other products are used as a solvent to clean electronics components, precision bearings, precision metals and so forth. That is maybe 150 million pounds.

Senator GORE. Okay. Did you say 450 for refrigerants?

Dr. GLAS. The discrepancy I just realized is that in the refrigerant segment 40 percent of that is 22, which is not a CFC, but I did include 22 in the refrigerant components, so if you would back out 40 percent of the 450, that is 180, so 270 is the refrigerant CFC component.

Senator GORE. I see. So, 40 percent of the refrigerant market is currently serviced by HCFC 22 which is not a CFC?

Dr. GLAS. Correct.

Senator GORE. So, 270—well, that still leaves a little. Where is the rest of it?

Dr. GLAS. There are some applications like use as a carrier gas for sterilization of hospital and medical supplies.

Senator GORE. As a what gas?

Dr. GLAS. It is called a sterilant gas by the industry. They use ethylene oxide and use 12 to carry it so that they will not explode, they will not have an explosion in their operation.

Senator GORE. What is the volume there?

Dr. GLAS. I would have to guess off this chart. Let me see, 4 percent. 4 percent of 700, 25 million, say.

Senator GORE. We are still missing 55 million pounds a year.

Dr. GLAS. Aerosol propellants account for about 40 million. Those are exempted applications for aerosol propellants.

Senator GORE. Okay. I am missing 15.

Dr. GLAS. It is in the arithmetic of the difference, I think.

Senator GORE. That is fine. The percentages worldwide would be different, correct?

Dr. GLAS. The distribution of applications is much different worldwide. Last year in Europe something over 40 percent of their total consumption was in aerosol propellants which has been virtually eliminated from the U.S.

In the rest of the world I would say the distribution is much more heavily towards refrigerant with the exception of Japan where their distribution is very similar to that of the United States, using a fairly large consumption of 113 as a cleaning agent for electronics products that we buy.

Senator GORE. So, they would resemble our distribution, but they would be tilted toward the cleaning agents?

Dr. GLAS. Slightly more toward the cleaning agents.

Senator GORE. And they have targeted the semiconductor market and that is responsible for their increase, correct?

Dr. GLAS. Correct.

Senator GORE. So, Europe is tilted heavily toward aerosol use?

Dr. GLAS. And that is changing very, very rapidly as most of the industries and consumers on a voluntary basis have agreed to phase out over about a two-year period beginning last December so that by the end of next year they are committed to phase out of aerosol production.

Senator GORE. Okay, let us go back to the U.S. market then. What I get is around 39 percent for refrigerants, 29 percent for foam blowing, 21 percent for chip cleaning and 11 percent for sterilizers, aerosol propellants, et cetera. We will make that a catchall category.

Dr. GLAS. That is roughly correct. And if you would like to have the numerical calculations, we would be glad to submit that later.

Senator GORE. I wish you would, and I would like to without objection include it in the record at this point.

In the refrigerant market, which ones are used? You have mentioned HCFC 22, but of the CFCs you have CFC 12 and CFC 11, correct?

Dr. GLAS. We can turn this chart back on and get an idea of it. The part in green is 12 and that is approximately 50 percent of the total refrigerant use if you include 22. You can see 11 there is about 5 percent and then the specialties are about 4 percent. The specialties include 115, 113, 114.

Senator GORE. Now, on foam blowing you do not have a similar chart for foam blowing, but for that 28 percent of the market, it is mainly CFC 11 and HCFC 123, correct?

Dr. GLAS. No, 123 would be a substitute. It would be 11, 12, and 113.

Senator GORE. All right. And for chip cleaning it is CFC 113?

Dr. GLAS. Largely, yes.

Senator GORE. For the sterilizers and aerosols?

Dr. GLAS. 12 and a little bit of 113.

Senator GORE. Now, let us look at the substitutes a little bit. What is the most promising substitute for CFC 11 at present?

Dr. GLAS. CFC 11 is used in refrigerants and is used in foam blowing. In the refrigerant segment, the only alternative we have to service existing equipment is the 123 that I described, the properties are very similar.

We are working on a retrofit program as I described hoping that with minor modifications to existing equipment we can make that existing equipment operate with 123. The largest segment is in foam blowing, and 11 is used in foam blowing for manufacture of polyurethane foams, the major portion of which business is for insulation products. Another large segment is for cushioning materials that would be used in automobile dashboards and seats.

For 11 used in urethane foams the industry is making a concerted effort to reduce the consumption through formulation technology changes, but once that is accomplished, the substitutes of choice have not been fully identified.

The most promising candidates today are 123 and/or 141(B).

Senator GORE. Okay. Now, when we took it out of the spray cans, what did we put in their place?

Dr. GLAS. The industry chose to put largely propane, butane, maybe some pentane, hydrocarbons.

Senator GORE. We were told before that they must pass that it could not be done.

Dr. GLAS. Industry changed their minds, did they not? They did it.

Senator GORE. Maybe that is what we ought to do this time. Maybe the same thing can happen.

Dr. GLAS. As I testified, Senator, we have described what alternative products we have to offer and beyond that it is really a societal question of which of the applications which consumes CFCs today we are willing to give up or we are willing to accommodate until these alternates can be fully commercialized.

Senator GORE. Well, that is not the only possibility. It may be that the sudden appearance of a major market for a substitute way to clean chips or to run an automobile air conditioner will put other companies into this business and create a completely different way of doing it.

It may not lead to the same profit stream for the companies that are making CFCs, and you have an interest in slowly making a transition to a market where you make a substitute that can be dropped into the same machinery, not interrupting the economy of your individual company.

But—let me just finish and I will give you a chance to respond—but if the nation as a whole or a group of nations decides that the environmental consequences of continuing this are just utterly unacceptable, and we say it has got to stop, then that presents your companies with a terrible market risk but greatly increases the chance that by some method whether your company's or some completely different process, the enormous money to be made will pull substitute technologies into the marketplace.

Now, why is it not reasonable to take that risk for your company, rather than to continue this utterly unacceptable risk for the world's environment?

Dr. GLAS. Our interest is in phasing out, Senator, as rapidly as possible. And if there are other industries which have solutions to the applications now in use, we certainly would welcome that.

Senator GORE. Even if it leads to bankruptcy for your company?

Dr. GLAS. It will not lead to bankruptcy for Dupont, when you realize that only two percent of our sales have to do with fluorocarbons. And we have stated, Senator, that we intend to phase out whatever the case.

So we certainly would encourage the societal mechanisms that can be put in place to operate as rapidly as they can for the users to make that transition, and we are offering an alternative through the technology we know how to make available.

And we described in our testimony that there are really two approaches to the applications development. One is that there very quickly needs to be a transition in the design of new equipment to use alternatives; and then secondly, there is a need to service the enormous capital inventory of equipment that consumes those products today.

Mr. BRASWELL. May I respond to your question?

Senator GORE. Yes.

Mr. BRASWELL. Our manufacturers, the people who are making the refrigeration equipment, they do not care what refrigerant they use. They would take a new refrigerant today and develop the equipment and produce it as quickly as possible.

For one reason the market would welcome it. Many of the users of this equipment today are nervous about what the future holds, and those people that are buying new equipment and installing it in supermarkets, installing it in office buildings, or whatever, would be much more content and much more satisfied if they could get a product which contained a non-environmentally damaging refrigerant, one that they could expect to have available indefinitely in the future.

So there is indeed a ready market for refrigeration equipment containing a new refrigerant. It is not the lack of desire on the part of the manufacturers which creates this problem of the time.

It is a matter of finding a satisfactory refrigerant, satisfactory from all points of view, one that will not destroy the equipment, one that is not toxic, not flammable, and also one which will continue to be efficient and will not give up efficiency gains. If we are going to use less efficient refrigerants, we are using more electric power. That has, of course, some implications for the greenhouse problem.

Senator GORE. Those are all stated in broad public policy terms, but they want the cheapest they can get, right, the cheapest to purchase and the cheapest to operate?

Mr. BRASWELL. Well, the refrigerant cost is a factor, but it is not a major factor in refrigeration equipment.

Senator GORE. The cost of the machine is the major factor?

Mr. BRASWELL. The machine is a factor indeed.

Senator GORE. But the current technology is the cheapest way to perform that task, as long as you do not have to pay anything to account for the enormous environmental damage that is done.

If the public decides that that damage is unacceptable and some alternative has to be found, then it might well develop that a more

expensive technology with a higher operating cost would have to be chosen. If it is out there, it does not have the economy of scale, it is more expensive, it is not going to be used.

If the current environmentally harmful technology is phased out and banned, then the alternatives might look attractive and might achieve an economy of scale and come down in costs. Is that not reasonable to suppose?

Mr. BRASWELL. Well, we are expecting the refrigerants to be sharply reduced and perhaps phased out. That expectation already exists within our industry. The only question is how long will it take us to get the new technology, the new refrigerants to use in satisfying the nation's needs.

And it is not just the manufacturers that are at issue here. It is the tremendous number of establishments which currently have this installed equipment that is going to need to be continued in service for many, many years. We cannot replace all of it in just a few years.

Senator GORE. Well, for every year we delay, that is another ten years of continuing damage to the ozone layer. So there is a multiple at work here.

Let me ask you this. Are you working, Dr. Glas—and I will address this to you also, Mr. Traflet. Are you working with automobile makers to make air conditioning systems more servicable and less prone to leakage?

If the answer is no, just say no.

Dr. GLAS. The answer is we are working with the automotive industry to supply the technology we know how to supply. When you are talking about leakage, that has to do with gasketing materials, and indeed one of our units which supplies elastomeric materials is working closely with the automotive industry to do that.

Our business is to supply the alternative refrigerants of the future, and there too we are working very closely with the automotive industry to accomplish that.

Senator GORE. Well, again there is the question of economics here. It is more expensive to use high quality hoses and fittings, but that is only because we do not put a dollar value on the destruction of the environment.

The fact is that a lot of the chemicals which you have produced that are out there being used right now in an environmentally destructive way could be handled more carefully, and the damage they do could be greatly reduced.

I have some questions on that. Are you working with the auto manufacturers and those who service automobiles to try to get new techniques for using your products in a way that results in less leakage to the environment?

Dr. GLAS. The technology exists to do that, and it is my understanding that one of the automotive companies has developed a service practice so that in their service stores there will be recovery equipment when the unit is serviced.

Senator GORE. But what about your responsibility? Here you are, you have made this stuff and you know that service stations all over the United States and all over the world are draining these chemicals out into open pans and letting them evaporate right into

the air and work their way up to the stratosphere to continue this damage.

Do you not have a responsibility, having discovered the terrible damage your chemicals are doing, to have an outreach program and to spend some money to educate and help change these environmentally irresponsible ways of handling your chemicals?

Dr. GLAS. We do have an outreach program, Senator.

Senator GORE. To service stations?

Dr. GLAS. We have a program by which we have said we will take the material back when it is available. There is a logistics problem of collecting it. As I said earlier, the technology is available to put it in place to collect it, and we certainly would encourage that be done as rapidly as possible.

Senator GORE. If I went down to the nearest service station to the Capitol here and talked to the guy in charge of it, would he know what you are talking about?

Dr. GLAS. It depends on which service station you go to.

Senator GORE. Would he have gotten a letter from you?

Dr. GLAS. He would not have, but you can go to a service station who would know about it.

Senator GORE. Why would not the one right down there have heard from you?

Dr. GLAS. They are not our customers.

Senator GORE. But they are using your chemicals.

Dr. GLAS. They may be using ours and they may be using someone else's.

Senator GORE. Well, they have not heard from anybody in the industry.

Mr. BRASWELL. Senator, may I respond? I do not represent the automotive manufacturers, but I am aware that the automotive people have worked very closely with EPA and have taken action and the automobile industry has taken action to train and to assist the automotive service people in doing just that, in recovering the refrigerants from air conditioners and automobiles, rather than venting them. And there is an active program under way that has been initiated by the automotive industry in that respect.

As far as our industry is concerned, our industry also—our manufacturers—are encouraging the contractors and dealers, the people who install and service the equipment, to take action to recover the refrigerants, to tighten up, to avoid leaks and minimize those leaks.

So there is a lot of activity going on to improve, to reduce the emissions and to improve the recovery of refrigerants in all of the equipment. There is a problem, as Dr. Glas mentioned, there is a problem in logistics. We do not have the infrastructure in this country established to collect, recover, and recycle refrigerant on a wide scale. But a lot has been done.

For example, in our association we have just published a new standard, a refrigerant standard, which defines the contamination standards for refrigerant for recycling purposes, so that everyone will know what must be done to the refrigerant when it is recycled in order to make it safe for reuse.

Senator GORE. When you tell them that they can take the chemicals back, that you will take it back from them, do you pay them for it?

Dr. GLAS. The program that I referred to earlier is one that we have just launched, and we would pay them for that product, less a service fee for cleaning it up.

Senator GORE. Do they get any money out of it?

Dr. GLAS. Yes.

Senator GORE. How much?

Dr. GLAS. It depends on the condition of the product, and we have not worked out a fee schedule at this point.

Senator GORE. So that has not been really established yet, has not been worked out yet?

Dr. GLAS. That is correct.

Senator GORE. Can they be recycled?

Dr. GLAS. They can be recycled if they can be cleaned up. If they can be cleaned up, we will do it. The question is how is it contaminated, and that is a technical hurdle that has to be dealt with.

Senator GORE. Well, we are going to be exploring every single pathway by which these chemicals get to the stratosphere. So I want to serve notice to you and others in here in your industry that the science of exactly how every single one of these chemicals gets up there to do the damage, we are going to be following them pathway by pathway.

And I believe that your industries have a responsibility not only to accelerate the development of alternatives, but also to help stop the release of these chemicals into the environment. Just because you put them out there does not mean you can wash your hands of them. They are still your responsibility, I believe.

Now, do you make the halons that go into these fire extinguishers?

Dr. GLAS. You will have to define a "fire extinguisher" for me.

Senator GORE. One that contains bromine-containing halon compounds.

Dr. GLAS. There are two types of halons. The type that we make is the type that is used in large installations for protection of computer equipment.

Senator GORE. Does it have bromines?

Dr. GLAS. It does have bromine in it. But we do not manufacture the type that are used in hand-held fire extinguishers.

Senator GORE. Are you working with that industry to develop substitutes, substitute ways to put out those fires?

Dr. GLAS. We are.

Senator GORE. What is the progress?

Dr. GLAS. The progress is slow. Our judgment is that no bromine-containing compound will be suitable as an alternative, and therefore there will have to be significant technology change.

Bromine has the characteristic of catalytically quenching the flame front. We know of no other technology approach to that, so that we do not have a solution in terms of chemicals.

It will take a system solution to provide an alternative other than carbon dioxide flooding.

Senator GORE. Now, what is the state of the patents on the CFC's?

Dr. GLAS. I can tell you the status of Dupont's patent position. I cannot speak to industry broadly, but we have a number of technologies which we have been developing, for which we were granted in 1988 ten patents.

Senator GORE. What about CFC-11, 12 and 113? What is the legal status of those compounds or processes that are important to their use?

Dr. GLAS. I am not aware of any patent on those compounds that is important in today's environment, that is which would restrict it as a technology to an owning company.

Senator GORE. Do any of your companies license any patents or technologies or proprietary information necessary for the production of CFC production plants by others?

Mr. TRAFLET. We have in the past. We have a policy, though, of not doing that in the future.

Senator GORE. Dr. Glas?

Dr. GLAS. We at Dupont have not and will not, except for a joint venture with Japan.

Senator GORE. Is this for a new CFC plant?

Dr. GLAS. We have had a joint venture with Japan for 40 years, and in the joint venture structure we have licensed the joint venture company which we own 50-50. But aside from that, we do not and will not license technology.

Senator GORE. Does that joint venture plant license technology?

Dr. GLAS. We have control over it and it does not and it will not.

Senator GORE. All right, very good.

All right, let me see now. Have you informed any industrial users of your intent to completely stop production of CFC's by the year 2000? And have you done so—have you told them that this is an absolutely firm date and that they cannot get any more of it from you after the year 2000?

Dr. GLAS. We have, and in our written testimony I believe we have included three of the types of communications that we make broadly to our customers and users. And in one or more of those, we have stated very clearly our policy to phase out by the turn of the century, which speaks once again, Senator, to your question about communications.

I agree with you that communications to the general public is essential. Many people on the street would tell you that they have stopped using CFC's years ago because they think about the aerosol ban and they think about the CFC's used in aerosols as being the only use for CFC's.

There is a very broad societal participation in the use of CFC's which we need to communicate. And for our part, in an attempt to get that communication out there, we have prepared a videotape which includes comments from scientists and environmentalists, which we will communicate as broadly as we can and which we hope will be picked up by the public television circuit, as an example, to communicate that need.

Senator GORE. All right, very good.

We are about to wrap up here. We have talked about a lot of the things that you should do. What in your view should individual citizens do if they wish to stop using CFC's? What do you recommend?

Mr. TRAFLET. Do you want me to answer?

Senator GORE. Yes.

Mr. TRAFLET. I think everyone has to be aware of the problem and be conscious of it. For example someone takes his air conditioner or his automobile air conditioner in to get it serviced, if it has a leak and he just fills it up and does not get it repaired, he is doing the environment a disservice. I think that is just typical of many of the things that could be done.

I think people have to be conscious of being able to recycle some of these things. We are doing a lot of work ourselves in terms of recycling of the 113 particularly.

I think that the government could be a help to us, both the EPA and the Congress, maybe helping to smooth the way, to make it easier for us to store these materials as we are bringing them back. You know, the RCRA laws do place some restrictions on how you can bring these materials back, and I think we could recycle a lot more if we simplified the RCRA laws in relationship to the 113.

You know, we have looked for permits in some places; it takes two years to get a permit to store a drum on a site. And if we could smooth that up a little bit, I think we could probably triple the amount of material we are bringing back to recycle now.

Senator GORE. Dr. Glas?

Dr. GLAS. The direct input that the citizen has is in the use of refrigerants in their automobile air conditioner, and it is really the only direct control he has. The proper maintenance of those machines is key.

Aside from that, the individual citizen needs to understand where these CFC's are used. While it is not directly a citizen, the government has a significant role to play in the management of CFC's. As an example, the government owns or leases some 455,000 office buildings or other buildings that are air conditioned.

Just in this complex on the Hill, there is a refrigerant demand of 20 to 30,000 tons of refrigerant capacity, and that capacity uses approximately a pound per ton. So if we are leaking typically a fourth, just this complex on the Hill is consuming roughly 7 to 10,000 pounds per year of 11 or 12. I could only guess. I would guess 11.

We have suggested in several previous occasions that there is an opportunity for the government to show real leadership to our society and to the world society by setting about a program to develop the retrofit technology for their existing equipment and to develop standards for the purchase of new air conditioning equipment that they may be using in new buildings.

And we, Dupont, would volunteer our resources to work with the appropriate agency in government to undertake the development of that retrofit technology as aggressively as we can.

Senator GORE. Mr. Braswell?

Mr. BRASWELL. As far as the citizen is concerned, I agree with Dr. Glas. Probably the most significant thing he could do would be to be aware of the consumption in the automobiles, because they are, the automobiles, are the major refrigerant users of this equipment.

I think there are some other things that the government can do. I mentioned those in my statement. The government can indeed

provide some assistance and research, and perhaps the best place for that is either in EPA, DOE, or particularly NIST.

I think someone needs to take a look at the funds that are being allocated for refrigerant research by the Federal Government for that purpose. I think that Dr. Glas' comment about having government undertake an exploration of retrofit of their installed equipment would certainly be a worthwhile initiative.

The industry indeed is going to do everything possible to help in finding ways to modify the equipment so that alternative refrigerants can be used in installed machinery. It is a very large problem. It is largely a problem for the industry to solve.

I think that the citizen should be very aware of what is going on. He should be aware of the equipment that he has and when he is disposing of equipment, such as refrigerators, he should be aware that it contains CFC's, not only in the compressor, for example, but also in the foam in the refrigerator.

Senator GORE. Well, let me just say in conclusion that I appreciate the testimony you all have presented here. We are going to have additional hearings, as I have said, and examine the science and technology of this question very, very closely.

I am left with the conclusion that we should completely phase out CFC's much more rapidly than currently contemplated. The Montreal Protocol should be amended and changed drastically.

And I believe, rather than shooting for phaseout by the year 2000, we should shoot for a phaseout within five years. I think that the appearance of a large mass market five years from now would lead to the rapid appearance of substitute technologies, just as occurred when we banned the use in spray cans.

The public never noticed the difference in that case, even though there were horror stories beforehand predicting that all of those uses would be denied to the public totally. It turned out not to be the case.

I understand in saying that that would pose a risk, not only to the companies here, but to the public, because of the possibility that some uses of these chemicals might temporarily be unavailable until the substitutes were there. But the risk that is on that side of the problem is very small compared to the risk of what we are doing to the world environment with these chemicals, which we know to be extremely large.

The first panel told us that it may be an even larger risk than we had thought before today's hearing.

In any event, we certainly appreciate the contributions of this second panel and of all our witnesses today. This hearing will stand adjourned.

[Whereupon, at 12:50 p.m., the subcommittee was adjourned.]

ADDITIONAL ARTICLES, LETTERS, AND STATEMENTS

Statement of the Society of the Plastics Industry

The Society of the Plastics Industry, Inc. (SPI), is pleased to have the opportunity to present our views on the challenges to the foam blowing industry posed by the phaseout of chlorofluorocarbons (CFCs).

SPI is the major national trade association for the plastic industry, and is composed of over 2,000 members, representing approximately 75% of the dollar volume of the sales of plastic in the United States. SPI members who are directly affected by the CFC issue are producers of CFC-blown foam products, polyurethane insulating spray foam contractors, and producers of raw materials used in the manufacture of chlorofluorocarbon-blown foams. These industries depend on CFCs.

The CFC-dependent portion of the foam-blowing industry largely consists of CFC-blown insulating products. These are rigid polyurethane (PUR) and polyisocyanurate (PIR) insulating foams and extruded polystyrene insulation products. The PUR/PIR and estruded polystyrene foams are used in a wide variety of applications, each with specific technical and market requirements. Major application areas are in the construction and refrigerated building and appliance industries. A wide variety of PUR/PIR foam products are manufactured for use in construction; these include insulation panels for roofs and walls, pipe insulation, spray and sealing foams. Extruded polystyrene insulation is used for commercial, industrial and residential structures. The primary function of these products is to provide insulation and, therefore, the thermal conductivity of the foam is very important.

In addition, products used in most construction applications must meet physical and combustibility property requirements that are specified by the construction standards of the various areas where the products are sold. PUR/PIR foams are also very important components of modern refrigeration technology. Rigid foam is used to insulate shipping containers, storage and processing warehouses and commercial/residential refrigerators and freezers. Here the foam provides not only good insulation but often contributes significantly to the structural integrity of the final product. The market success of rigid polyurethane, polyisocyanurate and polystryrene foam insulation is due to a variety of factors that include good physical properties and formulation versitility; however, the single most important factor is the excellent insulation properties that these products exhibit. The polyurethanes rely primarily on CFC–11; the extruded polystyrene insulation on CFC–12.

As the best insulating material (i.e., having lowest thermal conductivity) widely available, PUR/PIR and polystyrene thermal insulation make an important contribution to U.S. energy efficiency. These products, due to their energy efficiency, help achieve nationally important environmental goals with respect to energy savings. This includes Department of Energy (DOE)-mandated energy standards for appliances. In doing so, these products indirectly help minimize the problem of global warming, another significant environmental issue. CFCs are also used as an auxiliary blowing agent in certain flexible polyurethane foams, in insulated packaging for medical devices, cushion packaging for sensitive electronic equipment, and in other packaging applications.

COMMITMENT TO END USE OF FULLY HALOGENATED CFC'S

Despite the current dependence of the plastics foam blowing industry on CFCs, SPI's members are committed to environmental protection goals, and are engaged in large scale research efforts to reduce and eliminate, as quickly as possible, use of fully halogenated CFCs. This research dovetails with the associated efforts of CFC producers to develop alternative chemical substitutes which will be suitable for the various applications in the industry. Producers have been actively identifying alternative blowing agents since 1975. The foam plastics industry initiated its foam product testing as soon as the promising candidates were available in test quantities.

CRITERIA FOR ALTERNATIVE BLOWING AGENTS:

The challenges involved in identifying alternative compounds which can perform effectively as foam blowing agents begin with the review of the basic physical properties needed for the particular end use application and establishing a set of "performance criteria" against which the properties of candidate substitutes can be compared. In addition to effective performance as a blowing agent, the candidate alternatives must be environmentally acceptable and pose no unreasonable workplace hazard.

(1) Performance criteria

Performance criteria include appropriate volatility, nonreactivity, adequate solubility, effective head of vaporization, low vapor thermal conductivity, low diffusion rate, and non-corrosivity.

(2) Volatility

Volatility is the property most critical to the overall preformance of the blowing agent, and affects how it can be stored, handled and used in the process and how it will perform in the complex chemical physics of the polyurethane reaction—foaming process. On the one hand, too high a volatility will initiate an early blowing action, resulting in uncontrolled frothing, premature or undersized cell rupture and foam collapse as the cell gas expansion enters the polymerization reaction. On the other hand, too low a volatility, while it would simplify the handling of the blowing agent and the foam systems, would delay the blowing action required to balance the foaming and reaction kinetics.

(3) Non-reaction

Blowing agents must function physically in the foam system and foaming process and not undergo chemical reaction. Systems prepared with the blowing agent should have good shelf life, and should not later undergo a chemical breakdown in the foam product.

(4) Appropriate solubility

The blowing agent should be completely soluble in the pre-foam system (especially the B-side, or polyol-side of the system) yet be insoluble in the polyurethane polymer. If the blowing agent is insoluble in the pre-foam system, separate metering of the blowing agent to the mixing head is required. However, if the blowing agent is too strong a solvent for the polyurethane polymer, the foaming process will be slowed. An even more serious problem could result with the finished foam product if a significant portion of the cell gas redissolved back into the polymer, causing the cell walls to weaken and the foam to become soft and rubbery, and even collapse over time.

(5) Adequate heat absorption capacity

In addition to its expansion and insulation properties, the blowing agent also functions as a heat sink during foam manufacture to help control reaction and foam core temperatures. In the process of vaporizing, the liquid blowing agent absorbs some of the heat from the exothermic polymerization reaction. This controlling of the exotherm prevents thermal damage to the foam polymer structure which would otherwise occur.

(6) Low thermal conductivity

Of crucial importance in insulating foams is the thermal conductivity of the blowing agent, which contributes to the overall insulating value of the foam.

(7) Low diffusion rate

For long-term maintenance of thermal insulation efficiency of foams, a blowing agent with a low thermal conductivity must be retained in the foam cells.

(8) Environmental criteria

Fully halogenated blowing agents such as CFC–11 and CFC–12 meet the performance criteria outlined above. However, replacements for these chemicals are now being sought because the fully halogenated CFCs are contributing to stratospheric ozone depletion. Atmospheric research has identified two key factors which control the contribution of an individual CFC to ozone depletion. The first is the percentage by weight of chlorine in the compound, since it is chlorine which is implicated in the depletion. A second factor is the overall stability of the molecule in the atmos-

phere. Only for very stable compounds do significant quantities survive the trip to the stratosphere, where ultraviolet radiation causes the CFCs to release chlorine which reacts with ozone. It has been established that including a hydrogen atom in a chlorofluorocarbon molecule reduces the stability sufficient to dramatically lower the ozone depletion potential. Therefore the primary environmental criterion for any alternative is that it must either contain no chlorine or include at least one hydrogen atom.

Concern about the potential contribution of chlorofluorocarbons to warning of the earth's climate via a "greenhouse effect" imposes additional restrictions. Atmospheric lifetime plays an important role here as well. Inclusion of a hydrogen atom in a chlorofluorocarbon molecule lessens this concern. However, the contribution to warming is also influenced by the heat absorbing capability of the molecule.

(9) Feasibility criteria

In order to be accepted in the marketplace the alternative blowing agents must not pose unreasonable risks to life safety. Concerns are focused on two parameters: flammability and toxicity.

Flammability and combustion characteristics of the blowing agent are important for two reasons: First, if the blowing agent itself is flammable, then precautions must be exercised during blowing agent handling and during foam manufacture; secondly, different blowing agents will have different combustion characteristics which may contribute to the flammability of the foam.

Toxicity, like flammability, is of concern in both the manufacturing process and in the finished product. Several potential alternative blowing agents have been rejected on the basis of toxicity screening tests. Compounds which passed the screening tests and appear to be good candidates from a performance standpoint are now undergoing chronic toxicity testing. This testing involves a two-year exposure of animals; therefore, the overall research program requires approximately three-four years for completion.

Finally the product pricing for the alternative must be such that the insultation products into which it is incorporated can compete in the marketplace with other insulating materials.

VALUE OF PIR/PUR AND POLYSTYRENE FOAM PLASTICS INDUSTRY

Approximately 60,000 people are employed directly in the manufacture of polyurethane foam raw materials, systems rigid and flexible foams. Many thousands more jobs in downstream industries are also dependent on the foam plastics products produced for construction, refrigeration, furniture, bedding, automotive, boating and other industries.

Polyurethane chemical foam producting in 1986 totaled an estimated 2.3 billion pounds with an estimated value of more than $2 billion. An estimated total of 147 million pounds of CFCs were used as blowing agents in the production of polyurethane foams during 1986, with approximately 70% of that being used in rigid polyurethane materials designed for thermal insulation. Polystyrene resin foam production totaled an estimated 1.2 billion pounds in 1986 with an approximate value of $1.8 billion. Approximately 20 million pounds of CFCs were used to make the CFC-blown polystyrene foams.

STATUS OF FOAM INDUSTRY EFFORTS TO ADOPT CFC CONTROL STRATEGIES

Extruded polystyrene

SPI members, consistent with their pledge to move as quickly as possible to reduce and eventually eliminate reliance on fully halogenated CFCs, have adopted processing modifications and formula changes in many foam products to help achieve this goal. By the end of 1988, extruded polystyrene foam packaging manufacturers stopped using CFC–12, replacing it with hydrochlorofluorocarbon (HCFC)–22. (This food packaging is often referred to inaccurately as Styrofoam, Dow Chemical's trade name.) HCFC–22 has only 5% of the ozone depletion potential of CFC–12.

Extruded polystyrene insulation manufacturers are evaluating substitute blowing agents, from small research and development facilities to full-scale production units. (Due to the concentrated nature of the extruded ploystyrene insulation supplier industry, more specific information is not available as an industry matter. Information on efforts to reduce reliance on fully halogenated CFCs by extruded EPS producers can be obtained from the individual manufacturers.) The tempo of this research work has accelerated because of the increased availability of substitute HCFCs from the manufacturers.

A major manufacturer of extruded polystyrene insulation also announced in 1988 its intent to begin a global conversion of its Styrofoam brand polystyrene foam products from CFC–12 during 1989. That company plans to complete conversion in all of its products and plants as soon as it can be technically and commercially accomplished within the parameters of local requirements, such as building codes. Other CFC-blown extruded polystyrene insulation manufacturers also are engaged in research to find an alternative process.

Polyurethane/polyisocyanurate (pir/pur) foams

During the last three years the polyurethane industry has been engaged in intensive research programs to reduce its dependence on fully halogenated CFCs. Suppliers of fully halogenated CFCs have announced their intentions to cease producing these chemicals; the same companies are working feverishly to complete the development and testing of new blowing agents which are promising alternatives to CFC–12. Although small amounts of CFC–12 are used occasionally, the primary blowing agent used for the manufacture of PUR/PIR foams is CFR–11.

Considerable progress has been made; technical papers presented at the annual conferences sponsored by the SPI Polyurethane Division in 1986, 1987, and 1988 provide a record of the findings to date. These papers are collected in a monograph entitled, "CFCs and the Polyurethane Industry." A copy of that publication, together with an additional paper on the topic, are attached. Intensive research is continuing. The program for the SPI Polyurethane Division's 1989 Annual Conference will feature a number of scientific and technical papers on CFC-related research.

Manufacturers of flexible polyurethane foams are experimenting with increased use of water, new process technology and new raw material technology to reduce the use of fully halogenated CFCs in these products until effective, safe substitute blowing agents are available. In polyurethane packaging, the industry has drastically reduced and, in some instances, totally eliminated the use of CFC–11.

Foam manufacturers and suppliers of other raw materials are also testing possible chemical substitutes offered by producers to assess their performance in a variety of foam products currently made with fully-halogenated CFCs.

Two potential chemical alternatives for CFC–11 are being developed: HCFC 123 and HCFC 141b. Both chemicals are considered good alternative candidates to CFC–11 because they meet most of the requirements of a blowing agent and have a low ozone depletion potential, but the scientific consensus in that they are not "drop-in" replacements. Therefore, either the current manufacturing process must undergo a change or there must be a reformulation of polyurethane and polyisocyanurate foams to compensate for the different character of the alternative blowing agent. Short-term measures call for "stretching" the fully-halogenated CFCs. CFC "extenders" such as water or methylene chloride, may be used as partial blowing agents along with the CFCs.

HCFC–134a and HCFC–22 are potential replacements for CFC–12. Of these four potential substitutes, only HCFC–22 is presently commercially available. The use of higer levels of HCFC–22 also has potential for reducing CFC–11 usage in some formulations; however, the low boiling point makes it primarily suitable as a frothing agent and replacement for CFC–12.

Appliance insulation

HCFC–123 and 141b have been evaluated in appliance foam formulations and are reported to produce acceptable foams with some sacrifice in foam properties, especially thermal conductivity. Without compensating modifications in the foam formulations, substitutions of these alternatives will result in appliance foam having lower thermal insulation efficiency. The appliance industry is particularly faced with more severe challenges because of the recently-enacted Federal energy standards requiring further reduction in energy consumption of major appliances.

One blowing agent characteristic which is particularly important to the appliance industry is the non-reactivity of the blowing agent with the plastics used for the cabinet lining. A major shortcoming of HCFCs 141b and 123 is that they have a tendency to dissolve these liners.

Since the HCFCs are not going to be available in large enough quantities in the immediate future (probably not until the mid-1990's), attempts are bring made to reduce the consumption of CFC–11 in appliance foam by as much as 50% by a suitable combination of new technologies. Thus, new polymers are being developed to produce fine-celled foams without sacrifice of K-factors or non-shrink density. The increase in K-factor due to higher contribution of gas thermal conductivity with increased carbon dioxide content is partially offset by the lower radiative contribution of the new polymer technology.

Building and construction applications

For rigid polyurethane (PUR) and polyisocyannurate (PIR) foams, CFC-123 and CFC-141b are promising alternative blowing agents for CFC-11. After a careful evaluation of all the data generated on the PIR laminate foams with the said blowing agent systems, it appears that replacing all or part of CFC-11 in the formulations with CFC-141b to reduce CFC-11 usage may be the easiest thing to do as soon as large volumes are commercially available. CFC-123 is less promising as a total substitute for CFC-11, but blends of CFC-11/CFC-123 appear to be useful. The situation is similar for spray-applied polyurethane.

Since large volumes of CFC-141b may not be available until mid-1990, and that availability is contingent upon toxicity clearance, it appears that select CFC-11/water blends may be the best short-term answer to CFC-11 reduction in the PIR foams.

A number of problems are inherent, however, in the use of high levels of water in foam systems. Most serious is the decreased insulating performance of the foam as CFC-11 is replaced with carbon dioxide, a much better conductor of heat energy. Reduced foam flow during processing with increasing resin viscosity also limits the amount of chlorofluorocarbon that can be removed.

In addition, less efficient component mixing will be evident as system viscosity is raised, resulting in processing difficulties and coarser-celled foams. Adhesion to appliance cabinets (metal exterior, styrenics liner) when desired, will be adversely affected, as water addition tends to produce more friable foams exhibiting poorer adhesion capabilities. Finally, the proclivity of carbon dioxide to quickly diffuse out of the polyurethane foams puts greater demands on the structural integrity of the polymer. As internal cell pressure drops due to carbon dioxide effusion, foam shrinkage may occur due to the increasing pressure differential relative to the atmosphere.

Choice of catalysts and surfactant will play a key role in determining foam processing and properties as formulations rely increasingly on water to co-blow the foam. The proper balance of carbon dioxide generation, polymer gelation, and foam cure (internal versus surface) via catalysis contributes to systems of maximized flowability and foams with optimized cell-size, demoldability, dimensional stability, and adhesion. At the same time, fine tuning of surfactant type and level provides optimized air emulsification during mixing, component compatibility, and fluid dynamics during foaming to further reduce cell size and improve flowability and reactivity (and thus moldabilty and dimensional stability).

Flexible polyurethane foam

With regard to flexible foam, operating safety is a primary barrier to producing all water/TDI-blown flexible foams blow about 1.2 pcf due the very high bun temperatures that are encountered. Temperatures can become high enough to cause the foam to burst into flame the curing process. Chlorofluorocarbons, by acting as a heat sink prevent overheating of the bun, which can cause scorching in the foam and/or composition. Substantial increases in water and TDI levels are required to achieve small density reductions at these low densities. In addition, processing and foam performance properties suffer as the TDI level is increased. low density conventional foams made without auxiliary blowing agents have limited load latitude, tends to be hard and boardy and typically have poor durability. Foam splitting is a common problem if the index is lowered to try to produce softer foam.

New foam chemistry and processing technology have been developed in response to concerns about fully halogenated CFCs which reduce or eliminate the need for CFCs and other auxiliary blowing agents in the production of most flexible foams.

The effectiveness of CFC-11/methylene chloride blends and of HCFC-123 and 141b are also being studied; all appear to have potential as replacements for CFC-11.

BUILDING CODES

Many rigid foam applications require that the product passes specific combustibility tests. The type of test required and the severity of the test varies from area to area and according to the specific classification desired. Many different fire retardant foam formulations have been developed to satisfy these combustibility requirements. The effects of alternate blowing agents HCFCs 141b and 123 on the performance of foams in these tests have not been extensively reported. The issue is complicated by the large number of tests combined with the large number of formulations. Also, the lengthy process of obtaining the necessary product and code approvals can only begin after successful production trials have produced sufficient quantities for

prototype product testing. This can only occur towards the end of the product/process development cycle because the prototype samples must reflect actual intended product composition and performance.

JOINT INDUSTRY—GOVERNMENT RESEARCH EFFORTS

Laminate boardstock producers, their chemical suppliers, and their customers in the roofing industry are embarking on a major research program testing the performance of rigid polyurethane/polyisocyanurate thermal insulation manufactured with 123a and 141b. Performance of these products will be compared to that of CFC-11 blown materials. The trade association sponsors of this work are SPI's Polyurethane Division, the Polyisocyanurate Insulation Manufacturers Association (PIMA), and the National Roofing Contractors Association. The U.S. Department of Energy and the Environmental Protection Agency have been invited to join in the sponsorship of this program. The studies will be conducted at Oak Ridge National Laboratory. The study will be initiated in the spring of 1989 and will continue for three years. The study will demonstrate the effectiveness of the HCFC-blown materials as thermal insulators. Sponsors are optimistic that the new products will perform as well as the CFC-11 blown materials. SPI plans to co-sponsor similar types of research on other forms of polyurethane/polyisocyanurate insulation. Discussions with the SPI Polyurethane Spray Foam Contractors and with the Association of Home Appliance Manufacturers (AHAM) are in progress. Government co-sponsorship of these programs will also be welcomed.

CONCLUSION

The CFC-dependent portion of the foam-blowing industry largely consists of CFC-blown insulating products. Despite the current dependence of these products on fully halogenated CFCs, SPI's members are committed to environmental protection goals, and are engaged in large-scale research efforts to reduce and eliminate, as quickly as possible, use of fully halogenated CFCs.

The industry faces major challenges in finding acceptable alternative chemical blowing agents. A suitable alternative blowing agent must meet a number of criteria including performance, volatility, non-reactivity, appropriate solubility, adequate heat absorption capacity, low thermal conductivity, low diffusion rate, and, finally, environmental and feasibility criteria.

Companies in the multi-billion dollar foam industry have adopted processing modifications and formula changes in many products already to help achieve the goal of reduced use of fully halogenated CFCs. The extruded polystyrene foam packaging segment stopped using CFC-12 during 1988, replacing it with HCFC-22, which is a commercially available, drop in substitute. A major polystyrene insulation manufacturer also announced in 1988 its intent to begin a global conversion of its foam products from CFC-12 during 1989. In the polyurethane industry, considerable progress has been made over the last three years as the industry has been engaged in intensive research programs to reduce its dependence on fully halogenated CFCs.

SPI appreciates the opportunity to provide information on the challenges the industry faces in working to eliminate reliance on fully halogenated CFCs.

[From New Science, Feb. 1, 1989]

CHINESE BRING A CHILL TO BACKERS OF OZONE PROTOCOL

(By Jack Miller)

The Chinese authorities plan to raise the country's production of chlorofluorocarbons to 10 times its present level. Under the plan, China will by the year 2000 be producing as great a volume of CFCs as the US does today.

By raising its production of CFCs—which serve as refrigerants and insulating materials in refrigerators—China could undermine an international plan to reduce production and use of the chemicals, which deplete ozone in the stratosphere. The ozone at this altitude protects life on Earth from harmful solar radiation.

According to Cheng Zheng-Kang, a professor of law at Beijing University who helped to draft legislation to protect the country's environment, "China cannot afford to buy CFCs on the world market". Instead, Cheng said that China intends to make its own and raise production of CFC 11 and CFC 12—the two most widely used refrigerants—"from 0.005 kilograms per person per year at present to 0.05 kilograms per person per year by the end of this century".

Given estimates that China's population will rise to 1.32 billion by the year 2000 (This Week, last issue), this would raise annual production of CFCs to 132 million kilograms, making China one of the world's leading producers.

By contrast, the US, which produces CFCs in the greatest amounts, presently produces 1 kilogram of all CFCs per person per year, says Stephen Andersen, the chief of the technology and economics branch of the US's Environmental Protection Agency's Office of Global Change, based in Washington, DC. According to the Montreal Protocol of 1987, which signatories ratified recently, the US would be producing approximately 125 million kilograms of CFCs per year by 1998.

The Montreal protocol, which China did not sign, limits production of CFCs in "Article-5" countries [developing nations] to 0.3 kilograms per person.

Last week, Cheng told a conference on international law and global change at the University of Colorado at Denver that "according to 1987 statistics, China and the Third-world countries used only 2 per cent of CFC-11 and 3 per cent of CFC-12. Third-world countries cannot bear the responsibility for destroying the ozone layer. If the developed countries did not use so much CFC-11 and CFC-12, we wouldn't have a headache now," he said.

Cheng believes that the developed nations have to treat Third-world cousins as equals. "The Chinese government does not like the concept of 'special treatment' for developing nations," he said. "The Montreal protocol freezes production for the developed countries at half their 1986 production levels, or 2.5 kilograms per capita. The developing countries were limited to 0.3 kilograms of CFCs per capita."

Cheng believes, however, that the limits set on production by the protocol are equitable. "The Chinese government's approach to CFCs and ozone depletion," said Cheng, "rests on three points." These points, he said, concerned: first, the issue of who should solve the problems; secondly, accepting that developing countries have other problems besides environmental ones; and thirdly, the need to discuss openly the issues raised.

Current Chinese attitudes are also strongly influenced by the "Holocaust of the 1960s"—the Chinese cultural revolution. According to Jennifer Pyle, an American attorney who negotiates contracts in China, "the ability to be able to purchase consumer goods at last, along with a desire to live now, has resulted in a buying frenzy on the part of Chinese consumers. China's inflation rate of 60 per cent in 1988 added fuel to this frenzy," she said.

Refrigerators are now one of the most widely sought consumer items in China. More than 100 Chinese factories manufacture them, says Amory Lovins of the Rocky Mountain Institute. "During a five-year period in the early 1980s, the percentage of Beijing households with refrigerators rose from 2 to 3 per cent to more than 60 per cent," he said.

According to the Environmental Protection Agency in the US, Italian and Japanese companies are presently selling China obsolete equipment to make refrigerators. This means that China has to produce some CFCs to run them. Japan and Italy have both ratified the Montreal protocol.

Neil Olien, the chief of thermophysics with the US National Institute of Standards and Technology, says that inefficient refrigerators leak CFCs to the atmosphere from foam insulation in a refrigerator and that when these commodities are dumped, CFCs used as refrigerants evaporate into the atmosphere as well. The higher cost of replacements for CFCs will make it still harder for China to avoid using CFCs that destroy ozone in huge quantities, said Olien (see Technology, this issue).

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